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ZONAL ARRANGEMENT OF SOME GEOPHYSICAL AND PETROLOGICAL FEATURES IN JAPAN AND ITS ENVIRONS

By

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Abstract

Data on topography, gravity, earthquake seismology, and volcanic petrology are summarized for Japan and environs. They have a regular zonal arrangement along two chains of island arcs, one from Kamchatka, through the Kuriles, northeast Japan, and the Sitîtôs, to the Mariana Islands; the other from Kyûsyû through the Ryûkyû Islands to Taiwan. They include (1) foredeep, a proof of narrow downwarping, (2) gravity anomalies, the results of many years' movement of the crustal layer to date, (3) seismic velocity distribution, (4) strike of the seismic plane which slopes toward the continent, (5) distribution of younger volcanoes, and (6) hot springs (figures 1–3, and 6).

An attempt is made to represent numerically some characteristic of the basaltic rocks of Japanese volcanoes using the following formula:

$$\theta = SiO_2 - 47(Na_2O + K_2O)/Al_2O_3,$$

> where SiO_2 is expressed in weight % and other values in molecular proportion
> for chemically analyzed volcanic rocks.

One obtains nearly constant values for each volcano. The geographical distribution of the average θ is shown on figure 5. The distribution seems to be related to the zonal arrangement of geophysical features, especially to the depths of earthquake foci. That is, the deeper the earthquake foci, the more "alkalic" are the rocks erupted to the surface above the foci, and the shallower the more silicious and less "alkalic".

Further, the writer proposes grouping the volcanoes in Japan into two volcanic belts on the basis of zonal relationships: the East Japan Volcanic Belt and the West Japan Volcanic Belt, instead of the currently used volcanic zones.

Contents

I. Introduction

It is most important to study earthquakes and volcanic activity by physical means to determine their causes. Needless to say, however, unless the relations between earthquakes, volcanic activity, and other phenomena are made clear, the causes of each can not be ascertained. A close relation between geographical distribution of earthquakes and that of volcanic activity seems to exist. Most seismic foci and active volcanoes are situated along island arcs, where several other characteristic phenomena also manifest themselves.

The purpose of this paper is to describe the zonal structure developed in Japan and its environs and to give it importance in the interest of helping to find the causes of earthquakes and volcanic activity.

S. Tokuda (1918) was probably the first to point out a zonal arrangement of seismological, volcanological, and geological features. Among the most outstanding contributions concerning these feathres are those by K. Wadati (1928–1935) on deep-focus earthquakes and their distribution in Japan and environs and those by F. A. Vening Meinesz (1930-1934) on gravity surveys and the anomaly belt at sea around Indonesia. These studies were followed by discoveries of similar features in several other parts of the circumpacific island arcs and of the relations of a unilateral zonal arrangement of these features with respect to volcanic belts, shallow earthquake zones and others. The zonal structure of these geophysical and geological features in the circumpacific island arcs has become well known and is outlined in the book "Seismicity of the Earth" by B. Gutenberg and C. F. Richter (1954) and in other publications. The zonal arrangement displays a unilateral ordering of the following features, according to Gutenberg and Richter, " beginning on the convex side of the arc:

(A) An oceanic trench, trough, or foredeep.

(B) Shallow earthquakes and negative gravity anomalies, ⋯

(C) Maximum of positive gravity anomalies. Earthquakes at depths near 60 km., frequently large.

(D) The principal structural arc, of Late Cretaceous or of Tertiary age, with active or recently extinct volcanoes. Shocks at depths of the order of 100 km. Gravity anomalies decreasing.

(E) ⋯ Shocks at depths of 200-300 km.

(F) A belt of shocks at depths of 300-700 km."

In Japan and its environs, two zonal belts are developed. One extends from Kamchatka through the Kuriles, Hokkaidô, northeast Japan, the Sititôs (the Seven Islands of Izu) and the Ogasawara Guntô (the Bonin Islands) to the Marianas. It is the main subject of this paper. The other runs from Kyûsyû (Kyushu) through Okinawa (in the Ryûkyû Islands) to Taiwan (Formosa).

M. Minato, K. Yagi and M. Hunahashi (1956) put stress on the zonal struc-

tures in the Kuriles and the northeast Japan arcs taking geological features into consideration. They divided the belts into four zones, from the oceanic sides:

(4) Pacific ocean basin bordered by the Japan trough.

(3) Outer zone.

(2) Inner zone covered by a volcanic belt.

(1) Sea basins.

There are some differences of opinion between MINATO, YAGI and HUNAHASHI and the writer, as described in a preceding paper (SUGIMURA, 1958b).

Then, SUGIMURA (1958a) summarized the zonal arrangement in Japan and vicinity in the following outline. Also from the oceanic sides:

(1) Deep-sea furrow [(A) of GUTENBERG and RICHTER].

(2) Negative belt of gravity anomalies [(B)].

(3) The most active zone of seismicity.

(4) Positive belt of gravity anomalies [(C)].

(5) Late Cenozoic land masses of geanticlinal characters [(3) of MINATO, YAGI and HUNAHASHI].

(6) Girdle of active volcanoes [(D)].

(7) Late Cenozoic folded zone of geosynclinal characters.

(8) Sites of deep-focus earthquakes [(E) and (F)].

Much information on the zonal belts in Japan and its environs exists, but a synthetic study is lacking except the preceding ones. Hence the Japanese Islands may impress foreign geologists and geophysicists as having an intricate and complicated pattern. Of course, much research is still needed to obtain more facts on which a final synthesis of the structures can be based. However, a study of available data seems warranted at this time especially to facilitate research toward solution of problems concerning the mechanism of formation of magmas, seismic activity, and young orogenies which are common in circumpacific areas.

This paper gives the results of research carried on during 1956, 1957 and 1958 at the Geological Institute, Faculty of Science, University of Tokyo. A preliminary note on this work has already appeared (SUGIMURA, 1958b). The writer expresses his appreciation to Professors Chûji TSUBOI, Hisashi KUNO, Fuyuji TAKAI, Setumi MIYAMURA, and Akiho MIYASHIRO of the University of Tokyo for many helpful suggestions made throughout the course of his study. Special acknowledgment is due Professor KUNO for much encouragement and constructive criticism of the writer's attempt to express the θ-value of volcanic rocks. He has profited from numerous discussions with Messrs. Shigeo ARAMAKI, Fukutarô HORI, Tokihiko MATSUDA, Kazuaki NAKAMURA, and Masao YAMASAKI of the University of Tokyo. Among them, the writer is specially indebted to Mr. YAMASAKI for his invaluable advice and encouragement. He also wishes to express his gratitude to Dr. Gilbert CORWIN, the Pacific Geologic Surveys Section, for his discussion and kind advice concerning the manuscript.

II. Zonal arrangement of some geophysical features

The writer intends to show how selected geophysical features form a regular unilateral zonal arrangement along two chains of island arcs: one from Kamchatka, through the Kurile Islands, northeastern Japan, the Ogasawara Islands, and the Mariana Islands; the other from Kyûsyû in the westernmost part of Japan through the Ryûkyû Islands to Taiwan.

The selected features are (1) large-scale topography, (2) gravity anomalies, (3) seismic velocities, (4) seismic foci, (5) volcanoes, and (6) hot springs. The writer illustrates these features here. He prepared new maps of (1), (2), (4), and (5) instead of copying from the published ones, though (1), (2), (4) and (5) have already been pointed out as members of the zonal structures. Also, he added to them the remaining (3) and (6), which have not yet been pointed out as members of the zonal structures. Maps concerning (3) and (6) are copied from the original ones substantially as they were.

(1) Large-scale topography

Figure 1a represents large-scale topography in Japan and its environs on the basis of a map of the Maritime Safety Agency (1952). Land surface and sea floor shallower than 2000 m. are stippled, sea floor deeper than 6000 m. is blackened, and the remaining areas of intermediate depths are left blank. Blackened parts running near borders of the stippled area are the foredeeps. A principal foredeep runs from off Kamchatka through off Japan toward the Mariana Islands; an other smaller foredeep is off the Ryûkyû Islands.

(2) Distribution of gravity anomalies

Airy isostatic anomalies in Japan and its environs have ever been computed by W. HEISKANEN (1945). H. H. HESS (1948) published an isostatic anomaly map on the basis of the results. The writer, however, provided another isostatic anomaly map, because some results of more recent surveys were available.

Gravity surveys in Japan have been carried out by many workers, but for this study the writer used only the results of the following surveys.

Area	Author	Numbers of Stations
Throughout Japan	Ch. TSUBOI (1954)	about 4,500
Ôsima	I. YOKOYAMA and H. TAJIMA (1957)	1 (average of 66)
Titizima, Ogasawara	M. MATUYAMA (1935)	1
Sea	M. MATUYAMA (1936)	60

In relating the distribution of gravity anomalies to crustal movement, it is natural to determine isostatic gravity anomalies, because isostatic inequilibria cause or result from strains in the earth's crust. Consequently, one should compute isostatic anomalies in some manner. There is, however, a simple way to save the trouble of computing isostatic anomalies.

According to Ch. TSUBOI (personal communication, August, 1956.), the general magnitude of the Bouguer anomalies on the Japanese Islands are so much

larger than that of isostatic corrections derived from uneven topography, that an isostatic anomaly map is nearly the same as the Bouguer anomaly map. Also, according to Tsuboi, it is justifiable to regard the free-air anomalies as isostatic anomalies at sea, because isostatic reduction is largely canceled by the Bouguer reduction. For these two reasons, it may safely be assumed that the Bouguer anomalies on land and the free-air anomalies at sea represent approximate isostatic anomalies.

The Bouguer anomalies in the Japanese Island were calculated by Tsuboi (1954), where theoretical gravity at the proper latitude was computed using the 1930 international gravity formula. Free-air anomalies at sea were calculated by Matuyama (1936), but his theoretical gravity was computed using the 1901 Helmert formula. The writer has recalculated these anomalies on the basis of the theoretical gravity according to the 1930 international formula. The locations and resultant free-air anomalies of the stations at sea are shown in table 1.

Table 1.

φ	λ	$g_0-\gamma_0$ (m gal)	φ	λ	$g_0-\gamma_0$ (m gal)	φ	λ	$g_0-\gamma_0$ (m gal)
27°05′	142°11′	+341	33°37′	136°52′	− 15	36°13′	141°16′	+ 26
45	138 11	+ 27	38	139 15	+ 61	37 13	144 54	− 4
28 09	140 00	+ 68	34 10	140 00	+125	24	144 04	− 79
22	141 10	− 17	15	138 30	− 14	35	143 19	− 82
40	142 00	+209	17	137 32	− 2	58	141 59	+127
49	142 40	− 50	19	141 45	−238	38 56	145 59	+ 44
57	143 09	−138	31	140 50	− 32	57	145 54	+ 47
29 08	143 55	+ 50	45	139 25	+143*	39 13	144 56	+ 18
30 40	137 50	+ 32	46	143 31	+ 6	26	143 57	−145
50	139 00	+ 68	48	145 33	+ 21	35	143 05	− 32
31 00	140 10	+ 93	56	139 23	+ 9	40 24	147 18	+ 38
15	142 09	−252	57	139 30	(+ 17)	44	146 22	+ 51
20	141 15	+ 57	35 00	141 04	− 80	41 00	142 23	− 46
21	144 00	+ 30	03	141 54	−165	01	145 33	− 16
22	143 02	+ 11	05	141 54	−160	07	144 13	−139
33 00	142 59	+ 23	07	142 39	− 51	08	144 10	−144
01	137 28	+ 49	08	139 30	− 5	31	143 06	− 57
01	138 46	+ 80	10	144 40	+ 48	42 00	141 56	−122
01	142 01	−235	33	143 29	− 2	16	145 32	− 77
04	141 02	+139	38	143 09	− 37	45	145 04	+105
36	137 57	− 13	47	142 25	−101			

* Bouguer anomaly

Variation of the " isostatic anomaly " thus obtained over the Japanes Islands and adjacent areas is shown on figure 1b by means of contour lines with a contour interval of 100 milligals. The writer followed Tsuboi (1954) in drawing the contourlines on the islands except at one place, the northern coastal district around Sagami·Bay, where the writer made a modification to accord with the
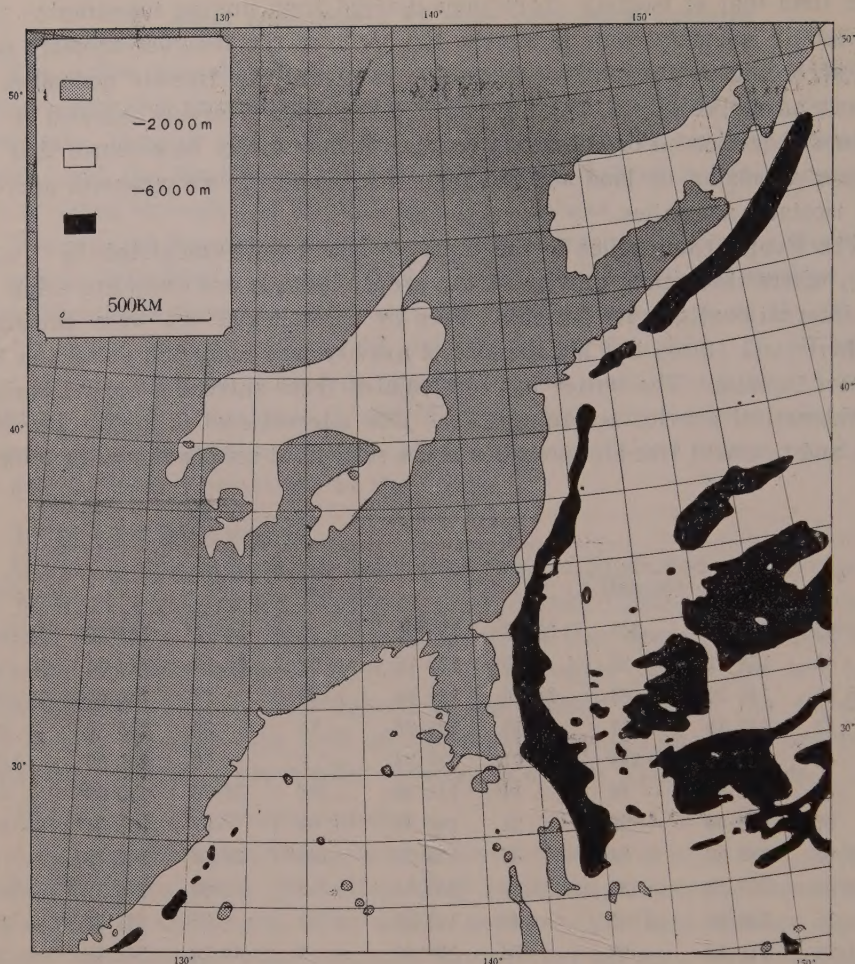
Figure 1. Zonal arrangement of some geophysical features of Japan.

a :   large-scale topography.

values at sea.

In figure 1b it is evident that nearly parallel positive and negative anomaly zones extend along the Kurile, the northeast Japan, and the Sititô-Mariana arcs. Further the zones are characterized by protrusions of the negative anomaly zone into breaks of the positive anomaly zone at Hokkaidô and Kantô (central Japan).

(3)   Regional variation of seismic velocity

In preparing time—distance diagrams of phase P, we can obtain differences between observed and calculated times of arrival at various stations. In figure 2, stations where the average difference is negative, that is, where the ground has higher velocity than standard seismic velocity, are indicated by open circles,
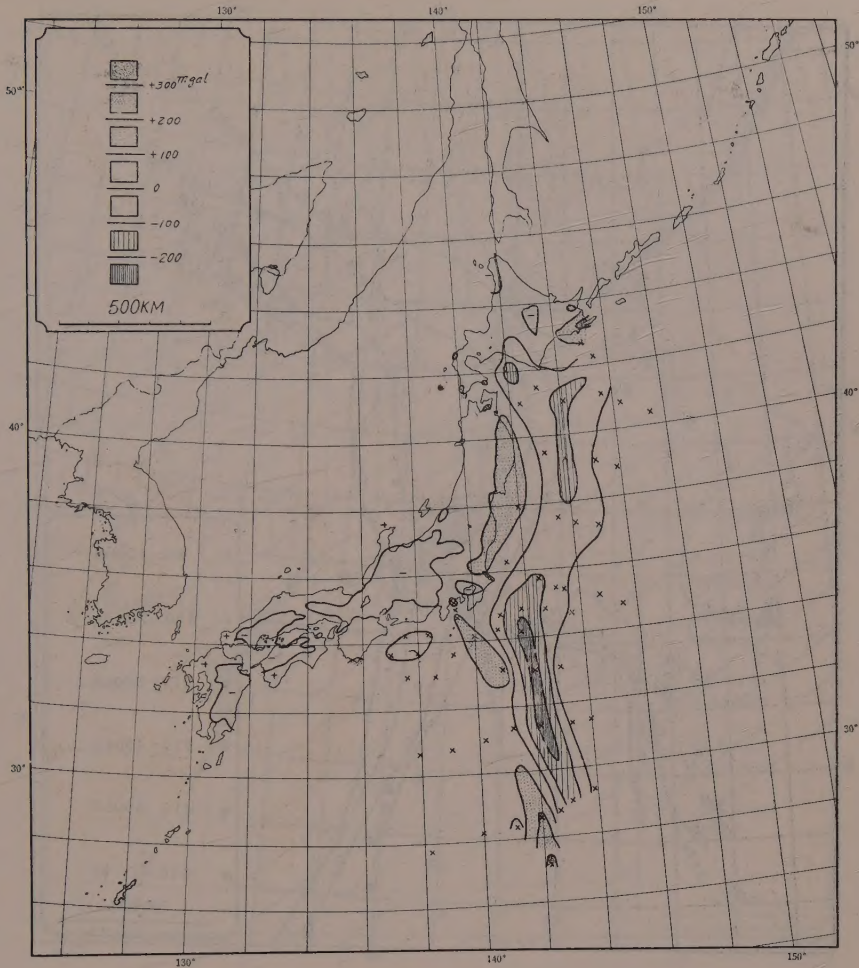
b: gravity "isostatic" anomalies.
The anomalies less than 100 mgal. are left blank, ir-
respective of + or −. These positive and negative
anomalies can be distinguished by the 0-lines and the
symbols + and −.

and stations where the average difference is positive, that is, where the ground
has lower velocity, are indicated by closed circles. Figure 2 is reproduced from
the figure of K. IIDA and T. KANBARA (1934), which was prepared on the basis
of earthquakes throughout Japan. The writer modified it only in omitting
values of the differences. K. IIDA and M. HAYAKAWA (1949) have confirmed
these results on the basis of recent information.

The resultant regional variation seems to the writer to be closely related
to the distribution of gravity anomalies. IIDA and KANBARA describe the highest
velocity in the Ogasawara Islands. The writer believes that it is related to a
conspicuous positive anomaly there.
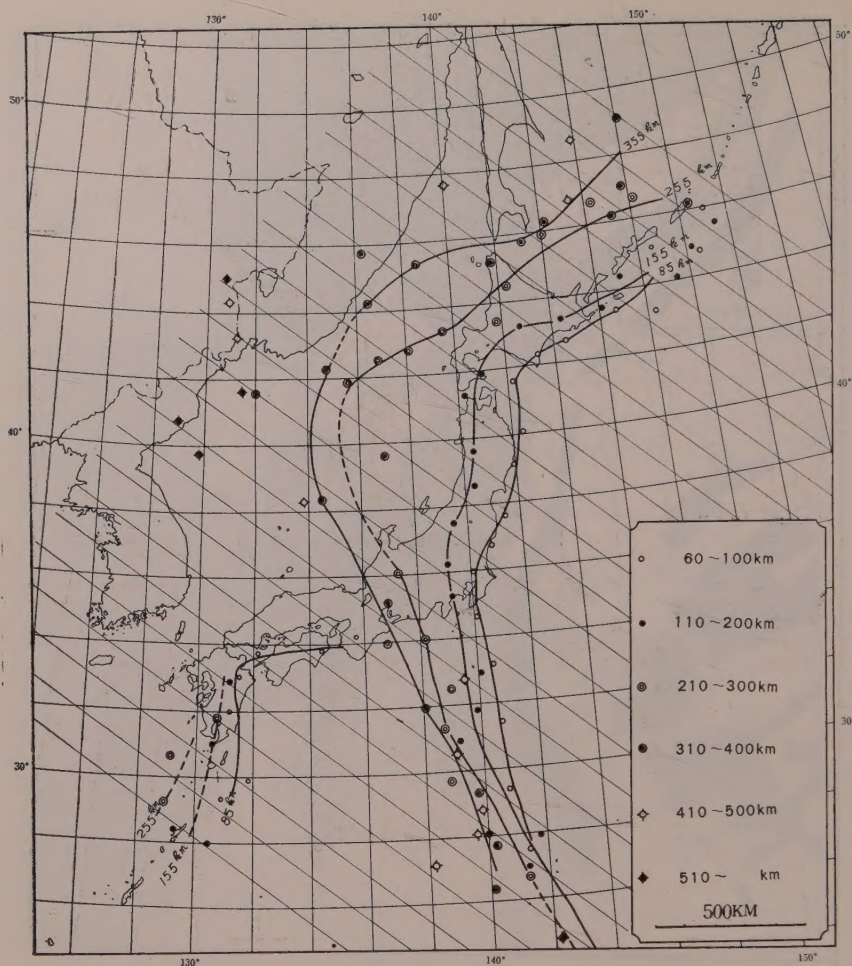
c: intermediate and deep seismic foci.

(4) Distribution of deep-focus earthquake epicenters

The epicenters of deep-focus earthquakes are distributed in two zones and delineate two planes which dip toward the continent below the Japanese Islands and surrounding areas. Isobaths for the seismic planes were published by K. WADATI (1935). The writer provided a similar but revised map. This is different from that of WADATI in method of plotting curves, and in using more recent information.

A distribution map of seismic foci deeper than 60 km., which have been observed in Japan during the period 1926 to 1956, was published by the Japan Meteorological Agency (1958) in Tokyo. On this map the locations of foci are indicated by symbols of depths for every 100 km. The writer partitioned the map into many strips, each of which is about 120 km. wide and runs from the northwest to the southeast, and plotted the middle points of the symbols in each strip (figure 1c). Then he plotted curves linking the comparable middle
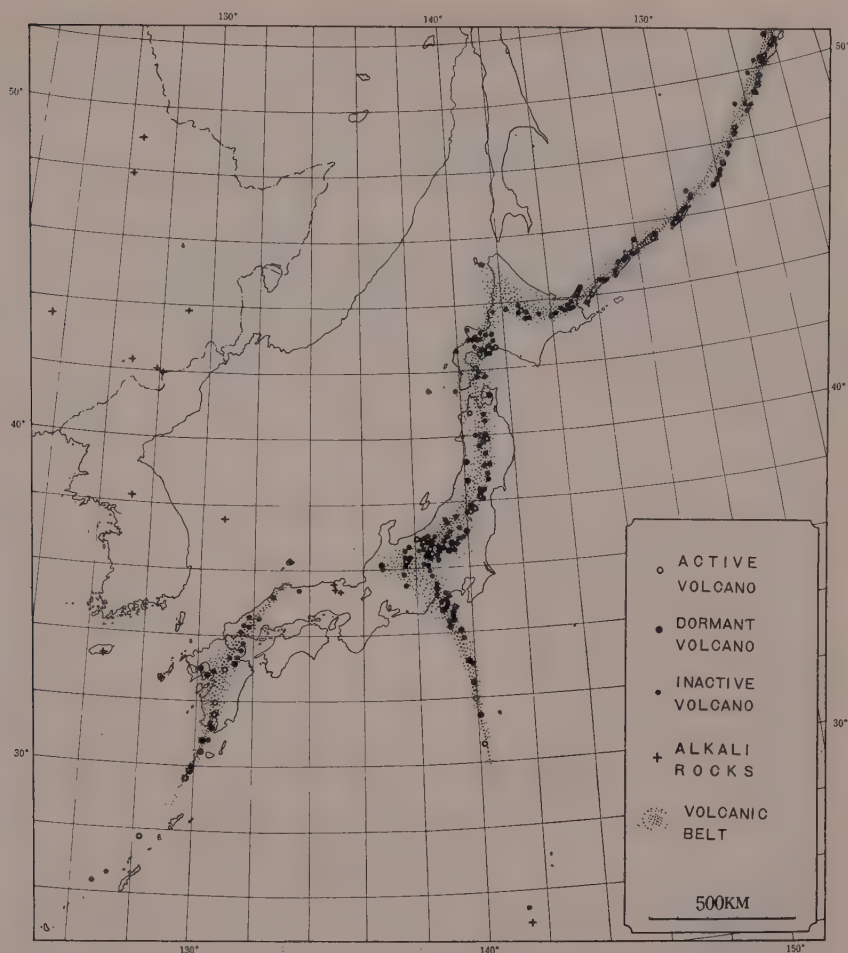
d: volcanoes and volcanic belts.

Volcanoes outside of the volcanic belts are those of alkali rocks.

points to each other on figure 1c, and regarded them as isobaths for seismic foci. The seismic plane in the area of the Kurile, northeast Japan, and the Sititô-Mariana island arcs slopes north-north-west in the northern part and west-south-west in the south, as can be seen on figure 1c. Although this relation can be seen also in the original map (J. M. A., 1958), it seems difficult to plot isobaths directly from the original map, because the seismic foci are scattered and the planes are conspicuously thick. However, linear and curvilinear rows of the middle points of the seismic zones display a fairly regular arrangement on figure 1c. Further, a result that is different from the map published by WADATI (1935) is that the northern extension of the Ryûkyû seismic zone has a bend in the vicinity of the Bungo Channel and extends to the Kii Peninsula on the east.

(5) Distribution of younger volcanoes

In the opinion of the writer, as alkali rocks do not show conspicuous zonal arrangement in general, it would be better that volcanoes consisting alkali rock series are excluded from a volcanic belt. Distribution maps of the Quaternary alkali volcanoes were published by T. Tomita (1935) and H. Kuno (1952; 1954). Here they are shown by + in figure 1d after Kuno (1954).

The Quaternary volcanoes consisting of the other rock series are shown on figure 1d, being classified into active volcanoes, dormant volcanoes, and inactive Quaternary volcanoes, irrespective of the rock series. An active volcano represents a volcano in which an eruption has taken place between 1850 and 1958, and a dormant volcano represents one in which an eruption has been recorded in historic time. The writer used information supplied by T. Minakami (1951) for active and dormant volcanoes, T. Ishikawa, K. Yagi, H. Kuno, Ry. Morimoto and S. Taneda (1955) for inactive volcanoes in the Japanese Islands, and T. Nemoto and T. Ishikawa (1955) for inactive ones in the Kurile Islands, except that he added some ones in the Kazan Rettô and the southern part of the Ryûkyû Islands, and revised a few on the basis of his own opinions and on accounts of very recent volcanic activity.

A glance at figure 1d, shows that most younger volcanoes in Japan and vicinity are located along two elongate strips. One can be followed from Kamchatka, through Japan and the Sititô-Mariana arcs; and the other runs from Kyûsyû through Okinawa and Taiwan. These strips are here defined as volcanic belts. The writer would propose two volcanic belts, the "East Japan Volcanic Belt" and the "West Japan Volcanic Belt", instead of the currently recognized volcanic zones.

An inspection of disposition of volcanoes within the volcanic belt

Figure 2.   Distribution of seismic velocities.

Closed circles: higher than the standard velocity; Open circles: lower than the standard velocity. After K. Iida and T. Kanbara (1934).

reveals that volcanoes are closely crowded near the eastern margin and sparsely scattered near the western margin of the belts. As a result, the eastern limits of the volcanic belts are relatively sharp but the western ones are not. In this relation it may safely be assumed that the volcanic activity is also more intense toward the east, and is most intense near the eastern limits. Thus the writer calls the eastern limits the "fronts of the volcanic belts" or the "tholeiitic fronts."

K. Wadati and Y. Iwai (1954) have emphasized a remarkable feature, that

is, the geographical coincidence between the distribution of the active vol-
canoes and that of the seismic foci of intermediate depths. In figures 1c and 1d
one can point out the sharp coincidence of the zones of the about 155 km.-deep
earthquakes with the "fronts of the volcanic belts." To indicate this coinci-
dence clearly, figure 1c is better than the figure of WADATI (1935) and the con-
cept of the fronts is better than the "volcanic zones."

(6)   Distribution of hot springs

The distribution of hot springs and cold mineral springs is given in figure
3 after T. FUKUTOMI (1937).   The figure is modified only in adding the above
"fronts of the volcanic belts" shown by the heavy lines.

A striking fact in this map is that east of the "fronts of the volcanic belts"
no hot springs with temperature above 30°C exist.

Figure 3.   Distribution of hot springs.

Closed circles: lower than 30°C; Open circles: higher
than 30°C; The larger circles: crowded hot springs. After
T. FUKUTOMI (1937).   The heavy lines; the "fronts of the
volcanic belts" of the present writer.

III.   An attempt to arrange volcanic rocks in the order of increasing θ-value

The writer follows genetic classification and opinions on the origin of vol-
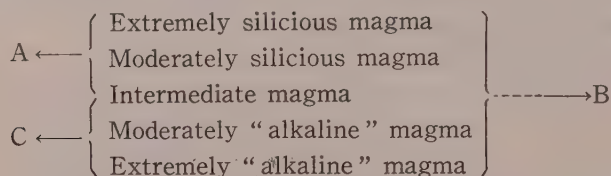canic rocks by H. KUNO (1956), which can be presented thus:

Tholeiite magma————————→A. Pigeonitic rock series

   →·······································→B. Hypersthenic or calc-alkali rock series

Alkali olivine basalt magma——→C. Alkali rock series

(where the solid arrow indicates fractional differentiation of magma, and
the dashed line indicates contamination process with granitic materials.)

Parental magmas of volcanic rocks are commonly grouped in two main types. However, magmas representing all gradations between the two typical types exist; there seems to be a nearly continuous series from tholeiitic to olivine-basaltic rocks. J. Green and A. Poldervaart (1955) conclude from a statistic consideration of chemical compositions of basalts that "there are no distinct types of basalt magma, but rather a continuous series from silica-saturated (tholeiitic) to silca-undersaturated (olivine-basaltic) rocks." M. Gorai (1957, figure 8 and p. 31) also shows that "compositions of basaltic rocks from various parts of the world are serial and can not be divided into two groups." These opinions are not contradictory to the Kuno's opinion, and the writer regards genetical relations between the above rock series as follows:

$$A \longleftarrow \left\{ \begin{array}{l} \text{Extremely silicious magma} \\ \text{Moderately silicious magma} \\ \text{Intermediate magma} \\ \text{Moderately "alkaline" magma} \\ \text{Extremely "alkaline" magma} \end{array} \right\} \text{-----} \longrightarrow B$$

(Significance of the solid and dashed lines is the same as given above.)

In order to represent the "alkalinity" of the various magmas, in which parental magmas of A and C and those of B are combined, the writer has devised a simple index calculated from chemical compositions of the volcanic rocks, though it may be a somewhat rough representation.

$\theta = SiO_2 - 47(Na_2O + K_2O)/Al_2O_3$,

where θ is the writer's index θ-value, and SiO_2 represents weight percentage of silica, and the other chemical symbols indicate molecular proportions.

The writer gives the following as basis for the formula.

L. R. Wager (1956) shows a series of interesting diagrams. The diagrams are variation curves of several oxides against an albite ratio which he defined as the molecular ratio of normative albite to plagioclase. In each diagram two curves of the alkaline series and the tholeiitic series are given. The most important chemical distinction between the series is the higher SiO_2 percentage in the tholeiitic series. That is, more SiO_2 is always contained in rocks of a given albite ratio from a tholeiitic series than in those of an identical ratio from an alkaline series. A. Rittmann (1953; 1958) drew similar diagrams for the Indonesian volcanoes.

A similar procedure is here applied to the Japanese volcanic rocks. The writer has taken the SiO_2 weight percentage for the ordinate, but has taken the molecular ratio of alkalies to alumina for the abscissa. The derived ratio indicates generally molecular proportion of normative alkali feldspars, expressing enrichment in alkalies in the crystallization sequence.

The writer drew such diagrams (e. g., figure 4a) for a score of volcanoes in Japan for which several analyses of each are available. A linear relation is revealed for many of the volcanoes. Then he picked out 10 volcanoes, Masyû, Akan, Risiri, Osima-ôsima, Asama, Huzi (=Fuji), Hatizyô, Ontake, Kuzyû, and
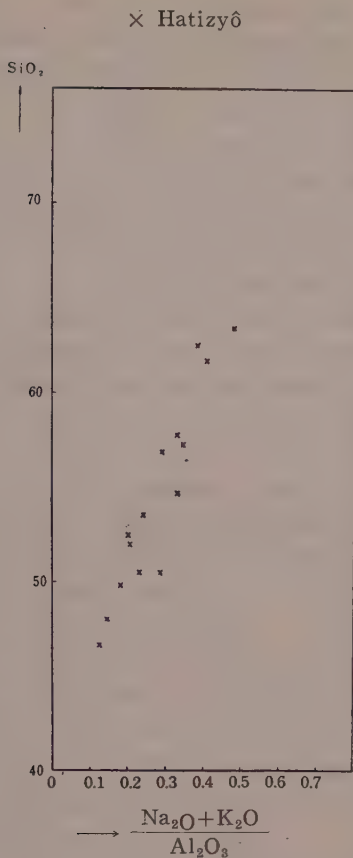
Figure 4a. Graphical plotting for Hatizyô Island of SiO_2 against molecular proportion: $(Na_2O+K_2O)/Al_2O_3$. Data are derived mostly from personal communications of Mr. N. Isshiki, and partly from H. Tsuya (1937), T. Katsura (1956), and N. Isshiki (1958).
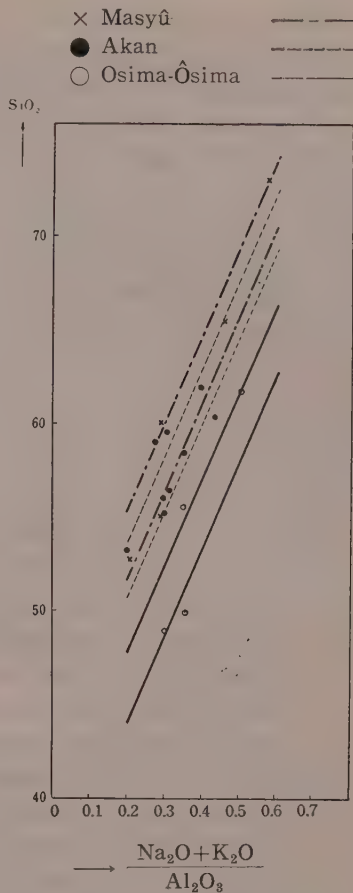
Figure 4b. Graphical plotting for Masyû, Akan, and Osima-ôsima volcanoes of SiO_2 against molecular proportion: $(Na_2O+K_2O)/Al_2O_3$. Data are derived from Y. Katsui (1950; 1952; 1955), and T. Katsura (1956).

Satunan-iô, as representative of Japanese volcanoes. From these he was able to produce a general formula common to all volcanoes in Japan.

The writer has given statistical treatments of the data. Using the method of least squares described by W. E. Deming (1946), the regression lines $y=a+bx$ are fitted to the data from each of these volcanoes, where $x=$the molecular proportion of $(Na_2O+K_2O)/Al_2O_3$ and $y=SiO_2$ weight percentage. The writer has obtained valnes b and the standard errors of estimate $\triangle b$. b gives the slope of the line. The 10 volcanoes have a common value $b=47$ within the limits of error $\triangle b$, or have a common slope of the trend lines, that is, the lines for these volcanoes are regarded nearly parallel each other. The writer proceeds from the premise that the trend lines for all volcanoes are parallel each other.

In figure 4b are provided examples showing the intervals in which the trend

lines can be drawn under this premise. The equations of the limits of the intervals are in the form $y=(a\pm\triangle a)+47x$, where the term a is the y intercept of the trend line having the standard error $\triangle a$. The true value of the intercept, α, lies on the interval $a\pm\triangle a$, or $a-\triangle a<\alpha<a+\triangle a$. a's for the regression lines can be calculated from the data of analyzed volcanic rocks. The standard errors $\triangle a$'s can be calculated from the data and results of H. W. FAIRBAIRN (1953). It may happen in figure 4b that the points are plotted outside the lines, because the lines don't indicate the intervals of the data, but the intervals of the regression lines. For the example used in figure 4b, the results show that the regression lines for Volcano Masyû and Volcano Akan can be the same, but the regression line for Volcano Osima-ôsimo is most probably different from the above two. From this it follows that one can discriminate the amount of SiO_2 in the parental magmas on the basis of the heights of the regression lines or the values of a.

Furthermore, values a become progressively and significantly smaller the more "alkaline" the rocks. This tendency agrees, as is expected, with the results shown by WAGER in which the SiO_2 percentage is lower in the alkaline series. A linear relation does not hold exactly for the extremely alkaline rocks, though the SiO_2 percentages are definitely lower. The material, methods and results used in the above study are fully described elsewhere (SUGIMURA, 1959).

To produce a general formula giving the index θ-value, the writer has taken a method based on the above diagrams. Here we assume that the volcanic rocks vary from basic to acidic always parallel to the line $y=a+47x$ in the diagram. Under this assumption, we may use the value a as the index of how silicious the paretal magma is. The writer calls it the "θ-value". θ is therefore computed according to the formula given at the beginning.

IV.   Geographic distribution of θ-value

Maps showing geographic distribution of the different rock series in the Japanese Quaternary volcanic rocks were published by KUNO (1952 ; 1954 ; 1956), from which distribution of the alkali rock series is copied into figure 1d. On his maps the area was divided into the discontinuous regions corresponding to the different rock series, but the writer has attempted to express the relations as a continuous areal variation from extremely silicious basalt to extremely "alkaline" basalt, because there are intermediate basalts as stated in the preceding chapter. The tendency that the Quaternary volcanic rocks in the Japanese Islands are more alkaline toward the continent has been pointed out already by many Japanese petrologists (e. g., S. TANEDA, 1951 · 1952; Y. KATSUI, 1954; T. ISHIKAWA and KATSUI, 1959), but there has been no attempt to arrange the rocks numerically. The writer investigated geographical distribution of the "θ-values" in the Japanese Quaternary volcanic rocks.

We may compute $\bar{\theta}$, an average of θ for a voicano, from which two or more analyses are known. The formula can be used even with one analysis, but obviously the more the better. Furthermore, it is natural that the more basic the

analyzed rocks, the nearer the calculated value is to that of the parental magma. The writer obtained $\bar{\theta}$'s of the volcanic rocks having $(Na_2O + K_2O)/Al_2O_3$ <0.4 exclusively (table 2). He also classified tentatively these volcanoes into

Table 2. θ-values and tentative grading of the volcanoes.

Name of volcano	θ-value		Inter-mediate	Moder-ately silicious	Extreme-ly silicious
	$\bar{\theta}$	Standard error**	31–35	36–40	41–
Alaid	36.1	±0.5		O	
Daiba	44				O
Masyû	43.7	±1.4			O
Akan	43				O
Risiri	34		O		
Tarumai	45.8	±0.4			O
Usu	42				O
Osima-ôsima	35		O		
Towada	41				O
Itinomegata	37			O	
Samukaze (Kampû)	36			O	
Nyohô-Akanagi	43				O
Nantai	41.5	±0.6			O
Akagi	44.9	±0.7			O
Asama	42.7	±0.8			O
Myôkô	39			O	
Iizuna	36			O	
Ontake	32		O		
Kayagatake	35		O		
Huzi (Fuji)	36.7	±0.4		O	
Asitaka	39			O	
Hakone	43.0	±0.5			O
Taga	41.9	±0.4			O
Usami	42.7	±0.3			O
Ômuro	39.2	±0.9		O	
Amagi	36.7	±0.4		O	
Ôsima	41.7	±0.5			O
Miyake	39			O	
Mikura	38			O	
Hatizyô	41.1	±0.4			O
Aogasima	42				O
Bayonnaise	44				O
Torisima	42.1	±0.2			O
Kitaiôsima	39			O	
Kuzyû	39			O	
Aso	37.9	±1.0		O	
Unzen	42				O
Kirisima	37.9	±1.2		O	
Satunan-iô	40			O	
Kuanyin (in Taiwan)	37.5	±1.1		O	
Wutalienchih (Godairenti)	(15.3)				
Paektusan (Hakutô)	(30)				
Dôgo	(33)				
Genbudô	(28)				
Kannabe	(34)		"Alkaline"		
Nagahama	(04)*				
Kasayama	(34)				
Iôsima (in Kazan Rettô)	(21)				
Penghu (Bôko)	(30.1)				

* Nepheline-bearing

** Standard error defined as $(\delta^2/n)^{1/2}$, where δ denotes the estimated standard deviation and n denotes the number of the samples.

intermediate, moderately silicious, and extremely silicious in accordance with the increase in value of $\bar{\theta}$. We may compare this part of the table, in which the more silicious rocks are to the right, with the geographical distribution of volcanoes, and one sees that they become more silicious toward the eastern margin of each volcanic belt (figure 5). In other words, one of the characteristic features of the geographical distribution of $\bar{\theta}$ is that the nearer the volcano is to the front of the volcanic belt the larger the θ-value becomes, or the more silicious the rock. To make the situation clear, the writer drew a sketchy isopleth map of $\bar{\theta}$ (figure 5).

Incidentally, for rocks of the alkali rock series, which are not exactly fitted to the formula, $\bar{\theta}$'s are also calculated using the same formula and added to table 2 and figure 5. They suggest approximate provisional θ-values.

In a recent paper, H. KUNO (1959) recognized three petrographic provinces in the Cenozoic volcanic fields of Japan and surrounding areas. He concluded that the boundary lines between the tholeiite and alkali provinces are located very closely to those between the areas where earthquakes occur at depths shallower than about 200 km. and those for deeper ones. It is almost the same as the conclusion of the writer. Discussions on the origin of the calc-alkali province are involved in the paper by KUNO.

Many suggestions towards the study of θ-value were provided by KUNO's past work, although this paper of the present writer and the paper of KUNO (1959) are independent each other. A preliminary oral communication on θ-value was given before (SUGIMURA, 1957).

There are some differences between the paper of KUNO and that of the writer. KUNO had collected a large amount of mineralogical evidence, but the writer made a first attempt to discriminate the types of the parental magma mathematically. KUNO has continued his research in the genesis of the igneous rocks, but the writer has been led into the igneous-rock field by the study of the zonal structure.

Moreover the results are slightly different from those of KUNO as follows:
1) KUNO divided discontinuously into petrographic provinces, but the writer postulated a continuous areal variation. The writer would emphasize his expression by means of evaluation.
2) KUNO divided the whole areas including where no volcano is known, but the writer divided into the volcanic belts and the nonvolcanic areas, and defined the sharp boundary line between the belt and the area as the " tholeiitic front ". It refers to a line tangent to the outermost known volcanoes and is believed to represent the approximate eastward limits of Quaternary volcanism.
3) The writer distinguishes discontinuous contiguity between the tholeiite and alkali provinces, from continuous contiguity as stated in 1). KUNO takes into consideration no such a difference. Insofar as the relation between the alkali province along the Sititô arc and the tholeiite province of southwest Japan concerns, the picture of discontinuous contiguity is nicely in accord with the distribution of earthquake foci.

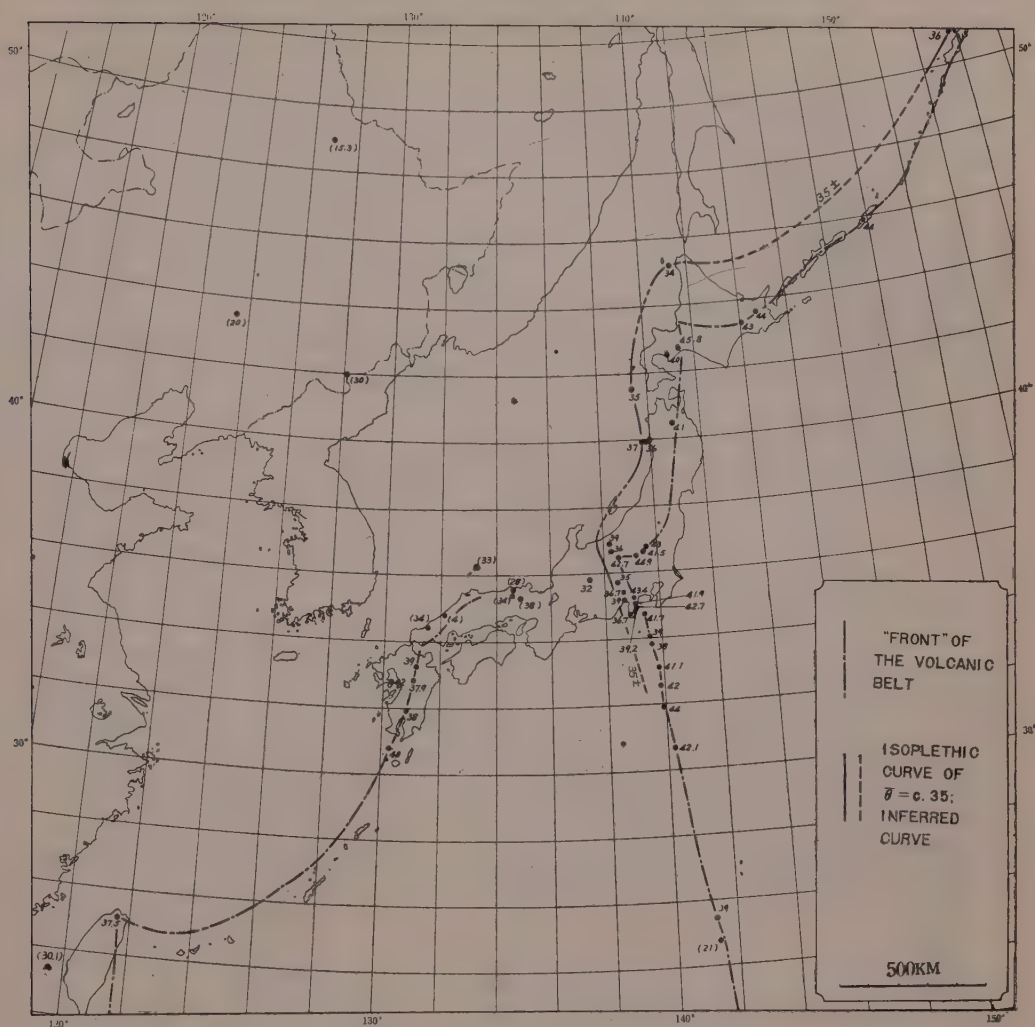Many deep- and intermediate-earthquake epicenters are known in and around

Figure 5.   Distribution of the θ-values.
In the parentheses : the cases of the alkali rocks.   Note
similar character in isopleth pattern to that of figure 1c.

Ise Bay in central Japan (e. g., Kuno, 1959, figure 11), but Kuno extends the
tholeiite province of southwest Japan to this part of the country (Kuno, 1959,
figure 8).   This discordance may be more adequately interpreted in terms of
discontinuous overlapping of planes than in terms of petrographic provinces.

V.   Conclusion

(1)   A simplified graphical compilation for the essential factors of the geophysi-
cal features described in chapter II, is provided in figure 6.
(2)   One may admit that the belts showing the most active endogenic processes
during the Quaternary, at least in Recent time, in Japan and its environs are
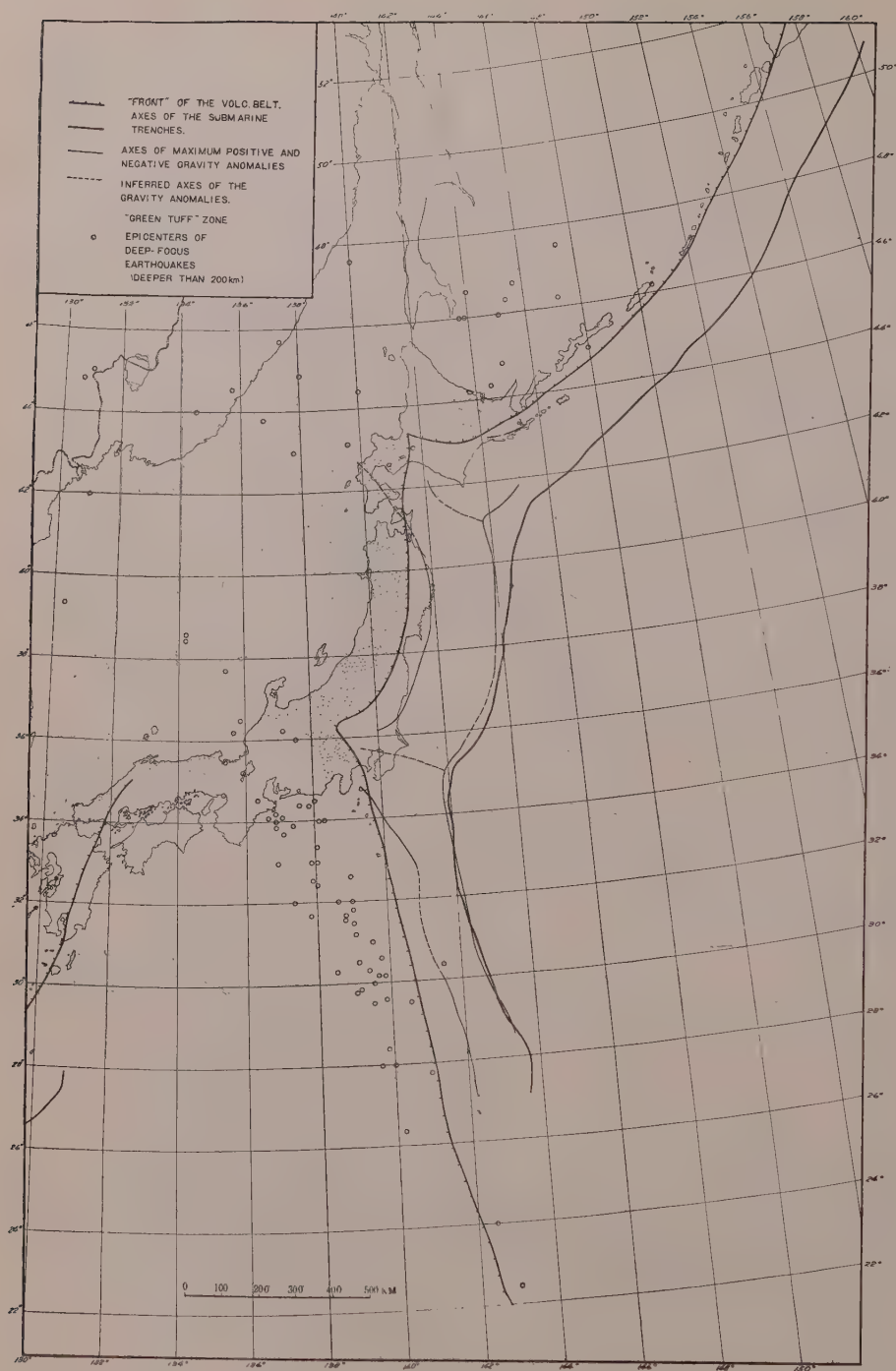
Figure 6. Geographical compilation for the geophysical and geological features in Japan and environs. The "Green Tuff" zone represents the area of thick Miocene volcanic materials.

two chains of island arcs, one from Kamchatka, through the Kuriles, northeastern Japan, the Sititôs, and the Marianas; the other from Kyûsyû through the Ryûkyû Islands, to Taiwan.

(3) It may be stated that they are orogenic belts in action. They are also characterized by some geological processes and events since Miocene (some part of which in figure 6). The writer would suggest that a younger orogenic movement started in Miocene and is now expressed by these two belts.

(4) The writer would propose two volcanic belts, the "East Japan Volcanic Belt" and the "West Japan Volcanic Belt", corresponding to the above two chains, instead of the currently recognized volcanic zones. Because the eastern boundaries of the volcanic belts are crowded with volcanoes and show relatively sharp lines, he calls them provisionally the "fronts of the volcanic belts" or the "tholeiitic fronts."

(5) As the parental magmas of volcanic rocks seem to form a continuous series from alkaline basaltic to tholeiitic ones, the writer made an attempt to represent it numerically (chapter III). When

$$\theta = SiO_2 - 47(Na_2O + K_2O)/Al_2O_3,$$

where SiO_2: weight %, the others: molecular proportion,

are calculated from chemical compositions of volcanic rocks, one obtains nearly constant values for each volcano (figure 4).

(6) The writer showed geographic distribution of the values in Japan and environs (chapter IV). The average $\bar{\theta}$ for each volcano shows the highest values at the "front", and lower ones the more distant the volcano from the "front."

(7) The isopleth pattern of the θ-value (figure 5) is similar to that of the depth of seismic foci ranging from 155 to 255 km. (figure 1c) and has the same trend of elongation. This is an attractive relation that should be studied with regard to the formation of magmas and the storing of seismic energy.

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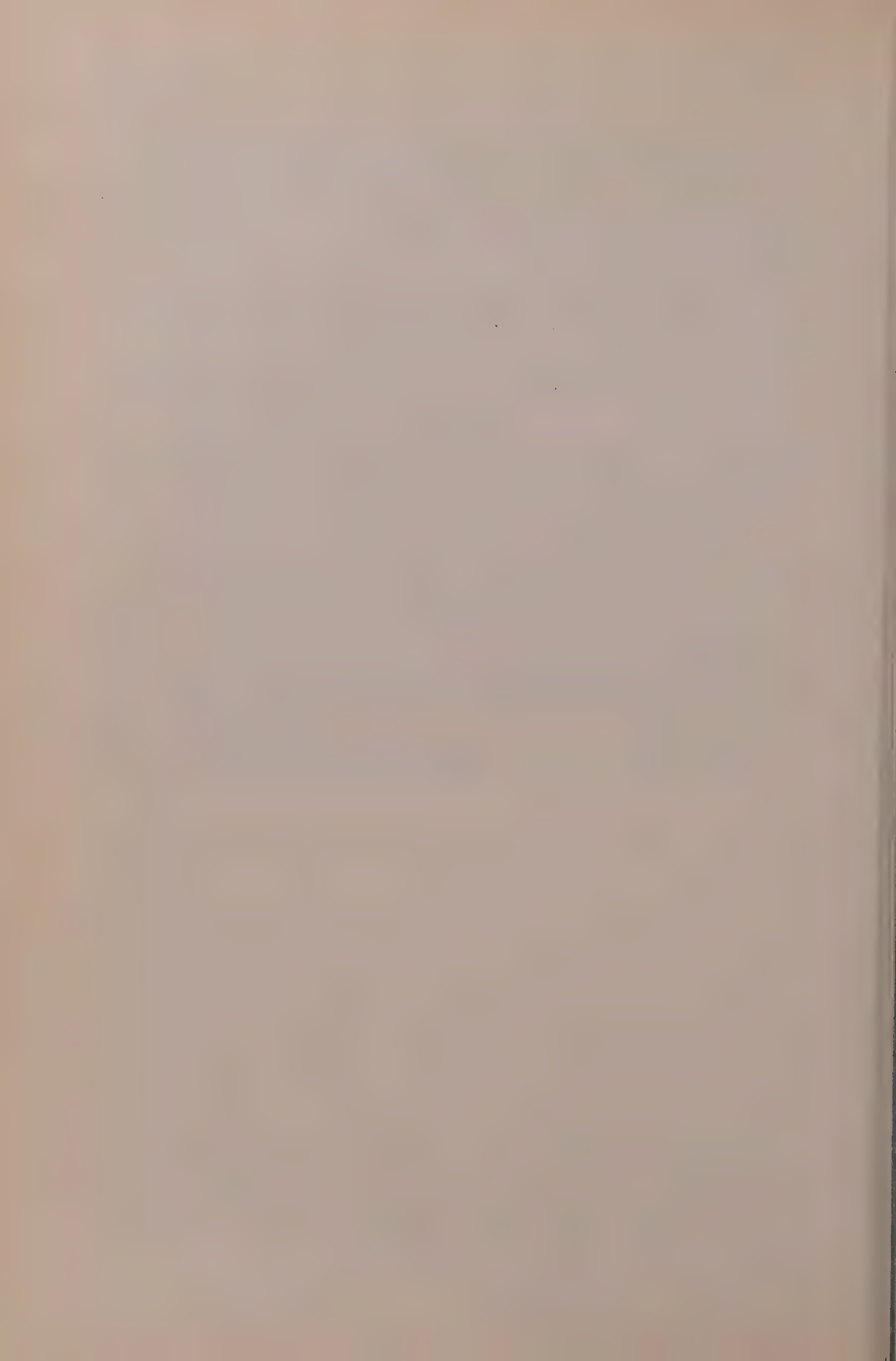
ROCK WEATHERING ON "TERRAS FIRMES" AND DEPOSITION ON "VÁRZEAS" IN THE AMAZON*

By

Takao SAKAMOTO

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Geologic map of the Lower Amazon Basin, Brazil

Abstract

" Terras firmes " and " várzeas "

The pre-Pleistocene ages were those of long continued planation, while the Pleistocene age was that of entrenchment. The contrast between plateaus and floodplains, that is, of " terras firmes " and " várzeas ", which is due to land forms appropriately called by geographers the " Amazon rias ", is an outcome of these processes during geological ages.

The lack of Pleistocene sediments in glacial tills, aeolian loess and volcanic ashes seems to have caused the very light load of the streams of the contemporary Amazon river system. This probably accounts for the limited area of " elevated " floodplains, and accordingly, the said contrast of plateaus and low floodplains.

Lateritization and forest-grassland boundary

The grasslands are found on sandy top soils. The sandy top soil can be either a layer of residual soil in a very thin veneer on clayey soil, or a bed of sedimentary sand deposit of considerable thickness. The process of formation of a residual soil with a sandy top layer seems to be intimately related with the process of lateritization.

When a drier climate of tropical savanna type sets in, a grassland first develops on the flatland but not on the slope. With the return of a wetter climate of equatorial type, the forest invades the grassland and even destroys the thick crust of iron and bauxite. The forest-grassland boundary seems to be controlled regionally by a climate, with a local but very important modification by geomorpholgy.

Origin of bauxite and manganese ore deposits

The bauxite deposits in the Amazon seem to be the product of a lateritization under savanna conditions in ages earlier than the Pleistocene.

The manganese deposits in Amapá seem to be the product of a lateritization under forest conditions that also dates back to earlier ages.

Predominance of quartz sands and kaolinite in recent sediments

Quartz sands and silts, and kaolinitic clay dominate not only the alluvium on "várzeas", but also the diluvium and even the Tertiary sediments constituting the low plateaus. Moreover, flatlands are frequently covered with the soil showing laterite profiles with the veneer of a top sandy layer.

And they have not been added and enriched with fresh rock dusts of glacial tills, etc. These are common sediments of the Pleistocene and are sources of alkalies and other mineral matters for soils on "elevated" floodplains of great agricultural lands in other parts of the world.

Introduction

The present work is the summary of the observations made by the writer en route on field trips during 1955-1957. During these years, he served under the Technical Assistance Program of UNESCO with the FAO-UNESCO Amazon Mission for the S. P. V. E. A.—Superintedência do Plano de Valorização Econômica da Amazônia, Government of Brazil.

The field work has been conducted mainly for the purpose of studying the iron, manganese, bauxite, phosphatic bauxite and evaporite - rock salt, anhydrite and gypsum - deposits in the Amazon. These ore deposits are described in separate reports which have been submitted to the Superintendent, S. P. V. E. A.

The writer has tried, in the present work, to view more the salient features in a general perspective from the sedimentological standpoint.

Owing to the limited time and quantitative data, however, this work is only an introduction to the sedimentology of the vast Amazon basin. It would be superfluous for the writer to diagnosticate too far on the basis of present inadequate informations.

Acknowledgments

1. Present erosion and sedimentation of the Rio Amazon

a. Natural levees

Natural levees are seen along the channels of tributaries as well as that of the main Amazon river where these run through floodplains.

Height of natural levees

Along the main Amazon continuous levees are found on both banks of the channel or channels, their height above the low water being 3-4 m near Santarém, 6-8 m near Itacoatiara and over 10 m near Manáus.

Along the tributaries, levees may be as high as over 8 m near the first rapid (primeira cachoeira), but usually 3-5 m downstream. It is usual for the tributaries, however, that they empty into lakes (lagos). In such lakes, the levees are gradually decreased in their height until they flatten out and disappear under the low water level. The water in lakes is then lead by rivers (rios or igarapés) out into natural canals (paranás) or the main Amazon. These igarapés and paranás again have levees on both sides which are 2-3 m above the low water level.

The natural levees become locally higher, often by over 1 m, on the concave bank of a meander, at the confluence of rivers or paranás, and on the banks of a narrowing channel.

The ground on top of these higher levees are usually chosen by the inhabitants as the favorite site of their houses. Even these houses have their floors raised above the ground by 0.5-1.5 m in order to keep away from occasional high floods.

Profile of natural levees

Natural levees show the following three types of profiles with the steep bluff wall facing the channel.

Fig. 1   Profile of natural levees

a. ANGULAR ASYMMETRIC   b. ROUNDED ASYMMETRIC   c.   FLAT
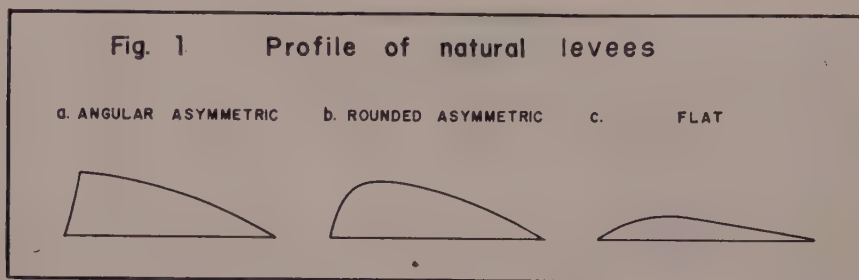
a.   Common type for the main Amazon and tributaries.
b.   Intermediate, annually inundated for a longer period of time.
c.   Found where tributaries empty into lakes and levees are about to be submerged under low water level, or inundated annually for the longest period of time.
Remarks: Vertical scale exaggerated.

Width of natural levees

The width of natural levees exposed above the water changes greatly with the fluctuation of the level of the river water.

During a dry season with the low water level, the width of the levees ranges from a few scores to a few hundreds of meters. As the water level is raised in a rainy season, the narrow stretch of land on the natural levees gets gradually submerged, with the width of dry land on the levees becoming rapidly reduced.

On the Ilha do Careiro at the confluence of the Rio Solimoes and Rio Negro, levees are higher and wider along the Paraná do Careiro which receives only the "água branca" of the Rio Solimoes, but levees are lower (by about 1 m) along the main Amazon whose water is the "água branca" of the Rio Solimoes much diluted by the "água preta" of the Rio Negro. A similar rule seems to hold true for the "várzeas" near the confluences of the main Amazon (água branca) in its lower courses with tributaries with água preta.

In the middle of June, 1957, which experienced one of the lowest level of maximum flood in recent years, the levees along the Paraná do Careiro were about 1-1.5 m above the flood level, and the dry land stretched for a few hundreds up to 1,000 m into the interior, and was extensively used as grazing land for cattle.

During the unusually high flood of 1953, the water is said to have reached about 2 m above the highest ground of the levee. This maximum height of flood water in 1953 was 14 m above the low water at Manáus.

The width of dry land on this Ilha, reaching 1,000 m during a flood time, is exceptionally great. In all "várzeas" the dry land on levees that can be

used for agricultural purposes is usually from a few scores to a few hundreds of meters wide, reaching only occasionally the width of 1,000 m during dry seasons.

The material of natural levees

The sediments with which natural levees are constructed are usually silt and fine sands on top of levees and gradually diminish in particle size and merge into clay down the gentle slope into lake or swamp bottom.

Along the Rio Trombetas, however, the natural levees are built of kaolin to the top. The compact mass of grayish white kaolin is consistent enough to form nearly vertical cliffs 3-4 m high above the low water, with perfectly smooth and beautiful curves conforming to the course of the channel as the river swings in open meanders. This is due to the lack in silt and sand sized sediments in the materials transported owing to the "half drowned" status of the potent river. This is also due to the overwhelming abundance of kaolinite due to long continued lateritization in the Amazon basin – the abundance perhaps unequalled by any other sedimentary basins in the world.
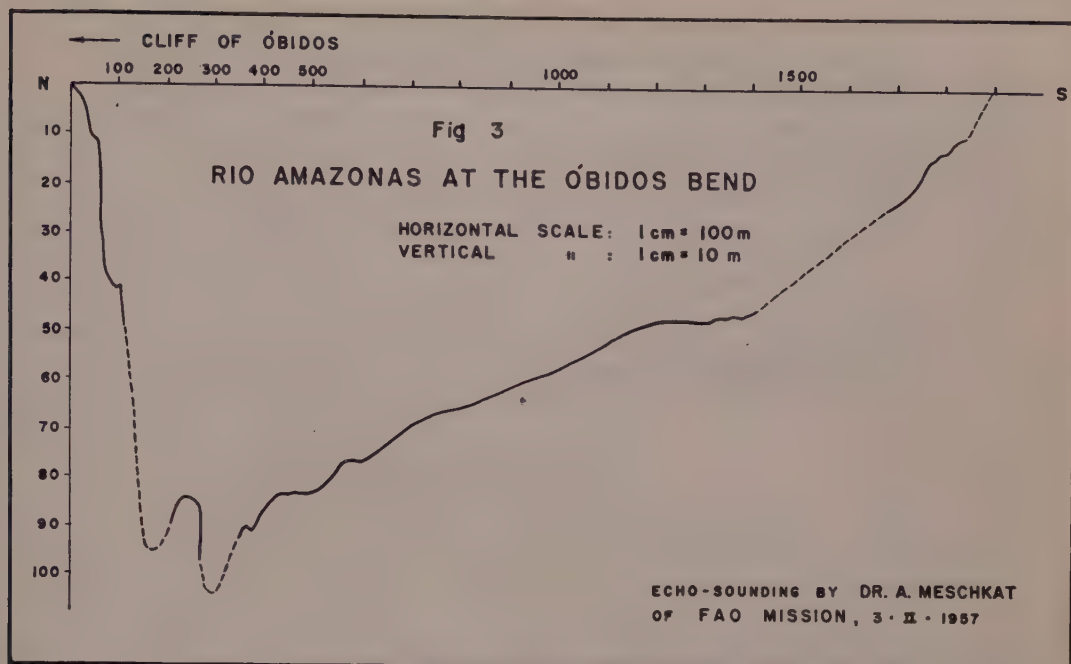
b. River profile

A cross section of the Rio Trombetas based upon our measurement of depths with an improvised weight and cord, is shown below:

Fig. 2 The profile of the Rio Trombetas (at a bend)
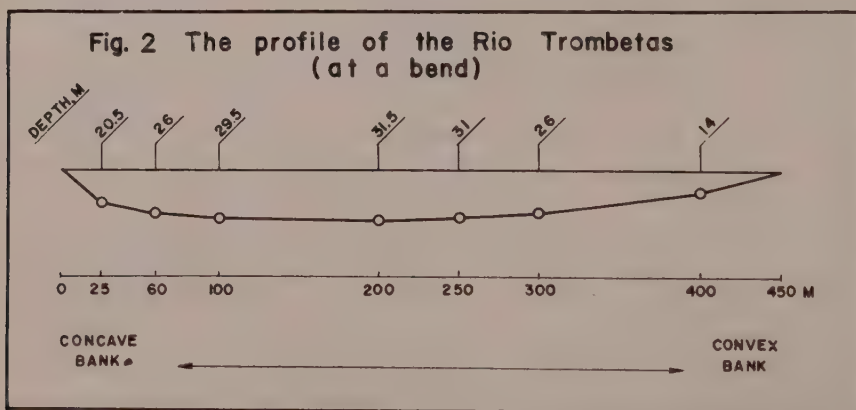
The cross section of the main Amazon at its neck at Óbidos is shown in Fig. 3.

These cross sections or profiles represent the usual asymmetric profile of a river at its bends.

A somewhat idealized profile of the Rio Amazon with natural levees, lakes (lagos) or swamps, showing erosional and depositional features, is illustrated in Fig. 4.

CLIFF OF ÓBIDOS

Fig 3

RIO AMAZONAS AT THE ÓBIDOS BEND

HORIZONTAL SCALE: 1 cm = 100 m
VERTICAL   " : 1 cm = 10 m

ECHO-SOUNDING BY DR. A. MESCHKAT
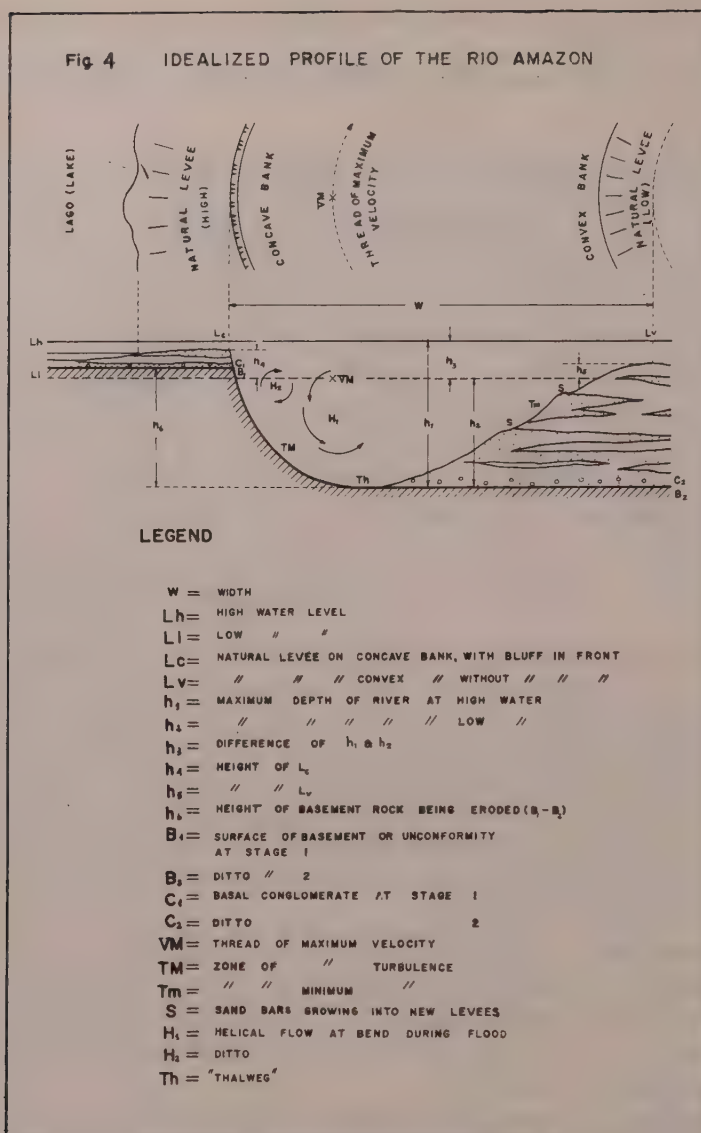OF FAO MISSION, 3·Ⅱ·1957

The natural levees on the concave bank at a bend is higher, as has been previously stated, due to the deposition of larger amount of comparatively coarse materials (silt and fine sands). This shows that there is stronger turbulence on the bottom in front of the concave bank, where coarse materials are plucked and lifted in suspension and transported upward along the wall of the bank. They get deposited as the water crosses over the top of natural levees and the turbulence is diminished.

The upwelling of the water mass has also been frequently observed by the writer along the concave bank even at low water level. So, the transportation of the coarser material upward is very probably helped by the upward current beside the turbulence. This upward current may represent a part of a helical flow of the stream water.

It is usually supposed, for the stream of a river, that water movement is in two helical flows in reaches and at crossings, and in one strong helical flow in bends.

It is the writer's impression that it may be possible that one of the two helical flows, that is the inside one when shifted closer to the concave bank together with the thread of maximum velocity, grows far larger and stronger than the other outside or closer to the concave bank, the second one, though pressed hard to the concave bank, seems to continue to function and to be responsible for the upward transportation of material for the building up of high natural levees.

The first one, which has grown larger and stronger is thought to push the bed load toward the convex side and downstream and also, disperse the large amount of suspended material. The suspended material is transported down-

Fig 4   IDEALIZED PROFILE OF THE RIO AMAZON

LEGEND

W = WIDTH
Lh = HIGH WATER LEVEL
Ll = LOW   "   "
Lc = NATURAL LEVÉE ON CONCAVE BANK, WITH BLUFF IN FRONT
Lv = "   "   " CONVEX   " WITHOUT "   "   "
h_1 = MAXIMUM DEPTH OF RIVER AT HIGH WATER
h_2 = "   "   "   "   "   " LOW   "
h_3 = DIFFERENCE OF h_1 & h_2
h_4 = HEIGHT OF L_c
h_5 = "   " L_v
h_6 = HEIGHT OF BASEMENT ROCK BEING ERODED ($B_1 - B_2$)
B_1 = SURFACE OF BASEMENT OR UNCONFORMITY AT STAGE 1
B_2 = DITTO "   2
C_1 = BASAL CONGLOMERATE AT STAGE 1
C_2 = DITTO   2
VM = THREAD OF MAXIMUM VELOCITY
TM = ZONE OF   "   TURBULENCE
Tm = "   "   MINIMUM   "
S = SAND BARS GROWING INTO NEW LEVEES
H_1 = HELICAL FLOW AT BEND DURING FLOOD
H_2 = DITTO
Th = "THALWEG"

stream by the flow and also moves sideways into quiet waters on the convex bank by the diffusion caused by the turbulence.

It is probable that both turbulence and helical flows are responsible for the subaquatic erosion and transportation in the channel of the Amazon river.

c. Subaquatic erosion and sedimentation

This erosion goes on in the concave bank, while sedimentation occurs on the convex bank. The difference of height h_6 (or $B_1 - B_2$) in Fig. 4 or approximately the maximum depth of the river corresponds to the height of the basement rock being reduced by the present cycle of erosion by this river.

It is noteworthy that an apparently sluggish, meandering river on a flat plain should be so potent an agency of erosion. A meandering river in the

Amazon is like a precision diamond saw applied to produce a perfect plane on an already flat and even surface of an object.

The subaquatic sand bars are first formed parallel to the convex bank (see b). Then they gradually grow up into a new levee running in front of an old one, leaving a paraná between them. This process of sedimentation along the convex bank is responsible for the usual, beautiful pattern of a number of smoothly running, sub-parallel levees and paranás on the " várzeas ", both on islands and on shores.

The sub-parallel arrangement of levees and paranás with not infrequent lagos (lakes), though beautiful sight from an aeroplane, presents rather serious problems in the land use on the whole " várzeas ".

d. Meandering and profile of equilibrium

The main Amazon

The meandering of the main Amazon appears to be more open and less sinuous than that of the Mississippi. This is perhaps due to the greater capacity of the Amazon due to the larger amount of discharge and less amount of bed loads of sand size.

The main Amazon is so wide that the thread of maximum velocity of the stream appears to be easily divided. So, it shows braiding into several channels, for instance, near Marajò Island, and Óbidos-Santarém. These braided streams often form narrow, but conspicuously smooth, open arcs of canals which are locally known as " paranás ". These canals do not show the tendency of meandering. This seems to be due to comparatively great capacity with the large amount of discharge, and stability and fineness of materials of the banks, which do not snpply too much of bed loads. " Neither erosion nor deposition " or " the profile of equilibrium " is usually thought to be a condition under which meandering is pronounced. Although the condition quite close to " neither erosion nor deposition " seems to obtain with the "paranás", it does not cause meandering.

The Rio Trombetas

The Rio Trombetas is " half drowned " in lakes. The levees form two rows of very narrow islands or narrow " dykes ", gradually becoming lower and occasionally getting submerged into the lake water. These levees and dykes are composed of kaolin. This river shows only very open meandering. The capacity is low, but the amount of bed load seems to be very small normally (only low sand bars are seen on shoals near Lago do Jacaré).

The Rios Maicurú, Curuá, Erepecurú

Incised meanders are seen at the first cachoeiras (rapids), but manifest meanders are observed where the rivers run through their flood plains within the Paleozoic and Tertiary Terrains. In these terrains, the rivers' competency is decreased but, the bed load of sands and silt is considered to be still large

(due to their attack agains soft banks).

<div align="center">The cause of meandering</div>

The meandering is developed in the above stated rivers by erosion on the concave bank and deposition on the convex bank.

The erosion on the concave bank is caused by the action (turbulence and helical flows) of a stream deviated obliquely from its course and made to attack the bank at higher angles.

The deviation is first caused by accumulation, on the bottom, of a load which the stream is no longer competent enough to transport due to the change in grade, etc.

In the upper course of a stream, natural hard rock bottom or large boulders may deviate the stream and cause a meander. But the banks with equally hard rock are not subject to erosion easily and do not yield sediments in any regular manner. There is no regular meandering.

In the lower course on a floodplain, large amount of sediments of sand and silt size tend to accumulate on the bottom. When the bank consists of materials which are easily subject to erosion, it supplies a great amount of load. This load supplied to the turbulent stream in a bend is carried for a short distance and deposited where turbulence is diminshed on the reaches, only to be the cause of further deviation of the stream.

Further downstream, where the bed load is substancially decreased and the bulk of the sediments is in suspension, there is almosf no obstacle of accumulated bottom load and hence very little meandering.

So, meandering is most manifest where bottom load of sand and silt size is freely supplied to the stream beyond the limit of its competency. So, the optimum condition for meandering is the free local supply of bottom load which can be eroded out of a bank and deposited on the bottom of the channel according to the alternately changing competency of the stream. The alternating change in competency is caused by alternate " bend and reach " or seasonal fluctuation of the amount of discharge.

In short, the optimum conditions for meandering are:

a)   a stream whose competency gets, at times, great enough to attack a bank but does not remain great enough to dispose the sediments supplied by the bank : and

b)   banks which consist of soft materials and are amenable to attack and supply freely to the stream a large amount of bed load, that is, sediments of sand and silt size.

In other words, the maximum meandering is a characteristic of those mature streams " which have a load so adjusted that the rivers are alternately filling and cutting their valleys ".

A mature stream is commonly defined as a stream so graded as to have a profile of equilibrium on which, theoretically, neither deposition nor erosion takes place.

A profile of equilibrium of a stream, so far as a " meandering " mature

river is concerned, however, should be understood to be a "profile with active erosion and deposition in equilibrium" instead of a "profile with no erosion nor deposition". The activity of such meandering rivers as an agency of planation can be understood by the profile of rivers in the Amazon shown in Fig. 4.

<div align="center">

2. Historical sketch of the processes of sedimentation in the Amazon basin during geologic ages

</div>

A. Pre-Pleistocene, the ages of planation

a. Sedimentation of the Paleozoic formation in the Amazon basin and planation in the interior

The stratigraphical succession of the Paleozoic formations is shown in the following columnar section:

Fig. 5   STRATIGRAPHICAL   SECTION   OF   GEOLOGICAL FORMATIONS   IN   THE   AMAZON   BASIN

AGES & FORMATIONS		THICKNESS (m)	COLUMNAR SECTION	LITHOLOGY
SYSTEM	FORMATION			
QUATERNARY		70		SANDS. SILT. CLAY
TERTIARY	BARREIRAS	600		SANDSTONE , SANDY SHALE (LIGHT RED TO PURPLISH)
CRETACEOUS	ALTER DO CHÃO	500		SANDY SHALE , SANDSTONE , CHERT (RED & WHITE)
PALEOZOIC — PENNSYLVANIAN	NOVA OLINDA	1500		ANHYDRITE, ROCK SALT / DIABASE / SHALE (REDDISH & GREENISH)
	ITAITUBA	450		LIMESTONE , ANHYDRITE , SHALE
MISSIS-SIPPIAN	MONTE ALEGRE	200		SANDSTONE (WHITE)
DEVONIAN	CURUA	350		BLACK SHALE, GREY SHALE
	MAICURU	350		ALTERNATION OF SANDSTONE & SHALE
SILURIAN	TROMBETAS	50		SLABBY SANDSTONE
PRE–CAMBRIAN BASEMENT				GRANITE, SYENITE, MIGMATITE, ETC.

These formations are characterized by the fineness of material and striking uniformity of lithology over extensive areas. Above all, the upper carboniferous Nova Olinda formation is characterized by thick evaporite beds, with their total thickness amounting to 640 m (rock salt: 360 m, anhydrite:

280 m) out of the total of about 1,200 m of the formation at Nova Olinda.

Sediments of fine material with uniformity of lithology over an extensive area indicate their provenance to be monotonously flat.

In the Cordillera Oriental to the northeast of Lima, Peru, there is found a thick sequence of dominantly marine Paleozoic formations.

Table 1. Sequence of the Paleozoic formations of Perú (20)

Age:	Group:	Thickness (m):
Permian	Mitu Group Red beds, volcanics	3,600
Permian & Pennsylvanian	Copacabana Group Limestone, black shale	1,900
Pennnsylvanian	Tarma Group Limestone, black shale	2,100
Mississippian	Ambo Group Sandstone, coal	800
Maximum composite total :		8,400
Pre-Mississippian	(Devonian & Ordovician) Excelsior Group, Cabanilla Shale, quartzite	" Tens of thousands of feet "

N. D. Newell et al state that, " Chronic's studies reveal close affinities between the Tarma faunas and those of the Pennsylvanian of the middle Amazon, in Brazil, described by Derby (1874).   Probably the Tarma sea flooded the mid-Andean trough and spread eastward along the Amazon trench " (20).

They also state that " the oldest fossils thus far found in Peru belong to the middle Ordovician...   Convincing evidence of early Paleozoic orogenesis (e. g. Taconian, Caledonian) generally is lacking in Bolivia and Peru ".   Upon this evidence they assume the basal complex of gneisses, schists and granitoid rocks to be probably pre-Cambrian.

These statements by Newell and his associates, give us an impression that formations other than Pennsylvanian in the Amazon also have their counterparts in Peru.   But the striking difference is in the fineness of sediments, and in the moderate but persistent thickness of formations in the Amazon and the large and rapidly changing ones in Peru.

Above all, a more detailed comparison of the Carboniferous sequence in the two areas attracts our attention.   The Carboniferous-Permian sequence in Peru as described by Newell, et al, represents, in my opinion (28), a complete orogenic cycle: coal measure (1)—neritic black shale with limestone (2)—land arkose or red beds (3).

    (3) Regression phase

    (2) Marine transgression phase

    (1) Fresh water transgression phase

In view of its great thickness (8400 m), this is a major orogenic cycle.

In the Amazon the evaporite-bearing Carboniferous, as encountered in the test oil well sunk by Petrobrás at Nova Olina, shows, in my opinion, at least four cycles of evaporite deposition in succession.

Nova Olinda formation   3 cycles with anhydrite and rock salt
Itaitúba formation   1 cycle with anhydrite and limestone
Monte Alégre formation   White sandstone with cross-bedding, with
                            plant remains

The Monte Alégre formation is sediments of shallow seas with strong currents and possibly partly of fresh water. Itaitúba and Nova Olinda formations are sediments in calm and nearly stagnant, inland sea water. This possibly represents a part of a major cycle, that is, Carboniferous-Permian.

Minor cycles are more pronounced. They start with fossiliferous* clay and silt, passing upward through beds of limestone and anhydrite, and end with those of rock salt.

These exactly correspond to the typical "IInd order cycle" found in the great salt sequence of Stassfurt, etc. in Germany.

As has been cited above, the Peruvian Cordilleran "trough" and the Amazonian "trench" were continuous at least at the time of the Pennsylvanian deposition, according to Newell, et al. It naturally follows that there must be some thresholds which nearly separate the "trench" from the "trough" during the deposition of evaporites. These thresholds consist of tectonic "highs" probably studded with islands. Slight submergence of the thresholds makes "sills" over which fresh sea water can circulate until the enviroment within the "trench" become habitable for fauna. A slight upheaval or overgrowth of corals may nearly close the thresholds so that the water mass within the "trench" not only becomes no more habitable but so saturated as to give rise to the precipitation of the series of evaporite.

The most striking contrast is that the Peruvian "trough" area developed into a major orogenic belt while the Amazonian "trench" area remained to be an area of secular epeirogenic movements. Upon the basis of the nature of sediments, we can reconstruct the tectonic set-up. Thus, we can visualize a featureless, flat terrain subjected to long continued denudation over the interior during the Paleozoic age.

b. Cycles of sedimentation in the State of Maranhão and intensive planation
    in the interior during Triassic and Cretaceous ages
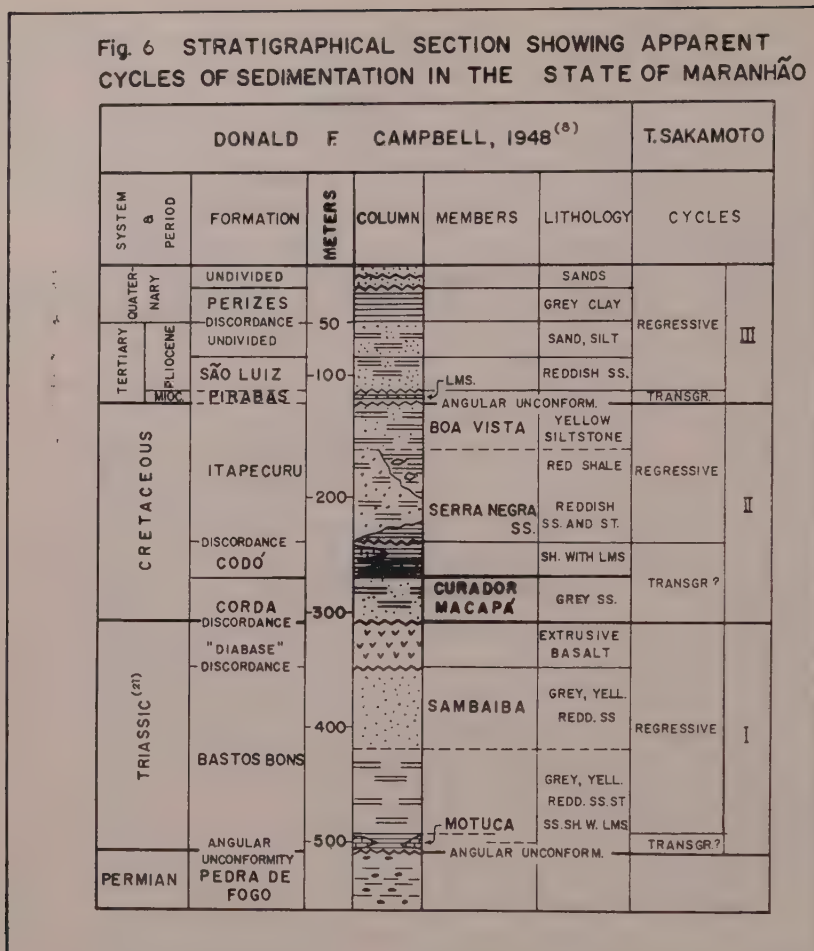
Maritime Regions

The stratigraphical succession of geological formations in the State of Maranhão is shown in the following columnar section:

The moderate total thickness and general fineness of the sediments—limestone, clay, silt and sands—suggest only gentle crustal movements. It is, however, the three apparently regular cycles of sedimentation recorded in the stratigraphic sequence that attracts our particular attention (See Fig. 6).

The Motuca and Sambaiba members, together with the extrusive diabase were assigned originally by D. F. Campbell as Cretaceous. According to

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* Spirifer rockymontanus Marcon, Streptorhyncus hallianus Derby (=Kiangsiella halliana (Derby)), Aviculopecten sp., Fusulinella Silvai sp. nov. Petri, Productus cf. Balesianus Derby, Ostrachod, etc.

Fig. 6 STRATIGRAPHICAL SECTION SHOWING APPARENT CYCLES OF SEDIMENTATION IN THE STATE OF MARANHÃO

SYSTEM & PERIOD		FORMATION	METERS	COLUMN	MEMBERS	LITHOLOGY	CYCLES (T. SAKAMOTO)	
QUATER-NARY	TERTIARY	UNDIVIDED				SANDS		III
		PERIZES				GREY CLAY	REGRESSIVE	
		DISCORDANCE — UNDIVIDED	50			SAND, SILT		
PLIOCENE		SÃO LUIZ	100			REDDISH SS.		
MIOC.		PIRABAS			LMS.		TRANSGR.	
					ANGULAR UNCONFORM.			
CRETACEOUS		ITAPECURU			BOA VISTA	YELLOW SILTSTONE	REGRESSIVE	II
			200			RED SHALE		
					SERRA NEGRA SS.	REDDISH SS. AND ST.		
		DISCORDANCE CODÓ				SH. WITH LMS		
		CORDA	300		CURADOR MACAPÁ	GREY SS.	TRANSGR ?	
		DISCORDANCE						
TRIASSIC[21]		"DIABASE"				EXTRUSIVE BASALT		I
		DISCORDANCE			SAMBAIBA	GREY, YELL. REDD. SS	REGRESSIVE	
			400					
		BASTOS BONS				GREY, YELL. REDD. SS. ST		
			500		MOTUCA	SS. SH. W. LMS		
		ANGULAR UNCONFORMITY			ANGULAR UNCONFORM.		TRANSGR.?	
PERMIAN		PEDRA DE FOGO						

Oliveira, however, these are considered to be older and probably of Triassic age (22).

The Motuca and Codò formations are sediments under shallow, brackish water in local, closed basins. Judging from their position (Parnaiba basin) close to the Atlantic coast it is possible that the deposition of these lacustrine sediments corresponds with contemporary marine invasions in the maritime regions.

If this is the case, each one of these cycles, is represented by facies of earlier transgressson and later regression. This succession conforms with what the present writer thinks to be the general rule for crustal deformations, both epeirogenic and orogenic (29).

The Triassic and especially Cretaceous formations are quite widespread in the interior of Brazil, being represented by almost flat-lying sandstone of continental deposition. Red and white sandstones of the Cretaceous group cap the plateaus ot the water divides of the Amazon, the São Francisco and the Paraná

rivers, suggesting its once much more extensive distribution over the continent in geological ages.

The sediments in the two cycles—Triassic and Cretaceous—in the State of Maranhão are possibly parts of their counterpart built on the maritime region of the continent locally subjected to the invasion of a shallow sea. The moderate thickness of the formations, the fineness of the apparent regularity of the cycles, all seem to point to secular and epeirogenic movements during these ages.

Interior regions

The extensive red and white sandstones, of which the nearly horizontal beds of sandstone capping the present plateaus along the divides are the remnants, are built back in the interior of the continent. Reddish color suggests warmth and general aridity at least over the low sedimentary basins. In fact, aeolian elements are not uncommon among these sediments. Under such condition, rivers are not competent enough to transport the coarser sediments for long distances. Sediments are simply spread over the plains close to the provenance. Such an arid inland, therefore, is an area of intensive planation.

There are also remnants of Cretaceous deposits within the present Amazon Valley: Alto-Tapajòs, Alter do Chão (in the oil well at the Depth-600 to 1050 m) and also in the oil wells at the depth of-2000 to 3800 m on and near the Marajò Island. So, the present Amazon valley, too, is very probably subjected to the process of general planation in this age.

c. Sedimentation and upheaval during the Tertiary age

Sedimentation

After the deposition of the Cretaceous sandstone of a regressive phase—Itapecurú Series—in the State of Maranhão, and also of the extensive and flat-lying red sandstone in the interior, there seems to follow a period of intensive denudation in the early Tertiary over the whole Amazon.

The downsinking graben of the Marajó Island is an exception, because here there is found a thick section of sediments supposed to belong to the Eocene and Oligocene ages (see next section d).

During the Miocene age, the maritime regions of the States of Maranhão and Pará were inundated by the sea, which deposited the so-called Pirabas formation in Maranhão and in the Bragança district in Pará. The thin marine deposits of this transgressive phase were followed by land sediments of the São Luiz series, etc. of the regressive phase. These later Tertiary sediments, although thin, represent a third cycle of epeirogenic sedimentation in Maranhão since the time of the Triassic age.

The extraordinarily extensive Tertiary sediments, filling the large basin of the middle and upper courses of the Amazon and stretching across the Colombian and Peruvian boundaries, are known as the Barreiras formation. These are lake deposits and supposed to be continental, the equivalent of the above stated marine Pirabas formation of the maritime regions. It is a little less

than 600 m thick both in the oil wells at Nova Olinda and Alter do Chão, a remarkably small thickness considering the vast area of its development.

The Barreiras formations, when followed westward, is known to give way to the Pebas formations in Peru which is lower stratigraphically and comprise marine, brackish and fresh water sediments (23).

The continental Barreiras formation is of variegated color—light rosy, pur-

Fig. 7   IDEALIZED CROSS SECTION OF THE AMAZON BASIN SHOWING SUCCESSIVE PLANATION AND ENTRENCHMENT
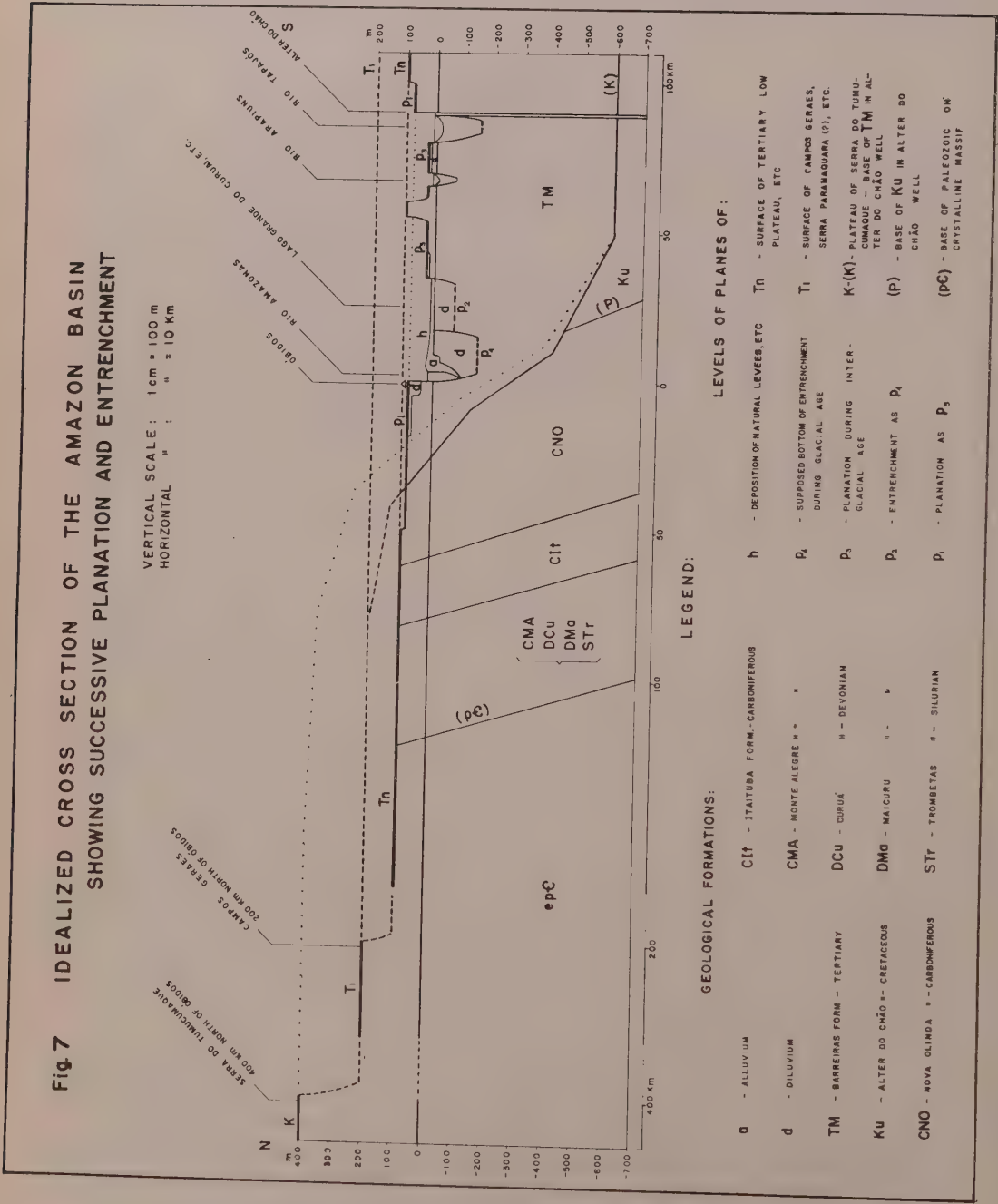
ple and white—, and is composed of kaolinitic shale and kaolinitic sandstone. The conspicuous feature is the predominating amount of kaolinite clay as the constituent.

Sandstones are usually heavily cross-bedded and grains are imperfectly sorted.

The nature of the sediments suggests a long continued lateritic weathering in the interior. While the texture of the sediments suggests a rapid filling and spreading over the vast expanse of the shallow inland basin, the transporting agency seems to be activated by intermittent downpours. Thus, it does not have the lasting capacity great enough to dispose the bulk of the sediments downstream.

So, the age of the sedimentation of the Barreiras formation seems probably to be another age of planation on a grand scale in the interior. (see levels of plains: $T_1 - T_n$ in Fig. 7).

Upheaval

It is generally accepted that a general upheaval took place in the later Tertiary age all around the coast of Brazil (except for the graben of the Marajó Island. See section d).

This is obvious because marine Miocene sediments are found inland in the State of Maranhão and along the coast of Nordestes of Brazil.

The coastal region of Pernambuco showed the tendency of upheaval after Pliocene by about 100 m (14).

The conspicuously rocky bottom of Rios Oiapoque, Maracaçumé, even near their mouths, seems to indicate that these areas remained positive or upheaving rather than negative or downsinking up to a recent age.

d. Sinking and filling in the graben of the Marajó Island.

Since 1949, three test wells for oil were sunk by CNP on and near the Marajó Island.

The depths of the crystalline basal complex are 3848 m (Cururú, Marajó Island), 4028 m (Limoeiro, basement not reached), 2182 m (Badajós, Rio Capim). The depths and formations encountered in the Cururú well are shown as follows:

It is remarkable that the Cretaceous (may be partly Triassic) and Tertiary formations should reach the thickness of about 4,000 m, when the total thickness of these strata reaches only 500 m in the neighboring State of Maranhão. So this narrow trough, running NNW-SE and, therefore across the course of the Amazon river, appears to deserve the name of a "graben".

Since there are no Paleozoic sediments above the crystalline basement and below the Cretaceous and Triassic, it is probable that the downsinking was initiated only after Mesozoic.

According to the Petrobrás record from wells, the Tertiary Barreiras formation is about 600 m at Nova Olinda, and the Tertiary and Cretaceous formations, put together, is 1050 m at Alter do Chão.

Fig. 8 GEOLOGICAL FORMATIONS ENCOUNTERED IN THE TEST WELLS FOR OIL ON & NEAR MARAJO ISLAND, PARA'

PETRI, 1954[24]			AMARAL, 1955[2]	
CURURU WELL			CORRELATION	LIMOEIRO WELL
THICK (m)	AGES	LITHOLOGY		LITHOLOGY
245	PLEISTOCENE	SILT		
460	MIOCENE	SILT, CLAY, FORAM.		
740		SILT, CLAY COAL & FORAM.	ZONE OF GLAUCONITE	NON-FACETED QUARTZ
	MIOCENE ?	MEDIUM TO COARSE SANDS		
		MORE SILT DOWNWARD	HORIZONTALLY BEDDED SILT & RED CLAY	
1692		PLANT & FORAM.		
2020	EOCENE-OLIGOCENE?	SILT, CLAY, PLANT		
	EOCENE ?	FINE SANDS		FACETED
2580		LIGNITE		
	CRETACEOUS	MEDIUM TO COARSE SANDS	CROSS-BEDDED FELDSPATHIC SANDS	FELD-SPARS QUARTZ
3507		ALGAE		
3848	CRETACEOUS W. DIABASE	FINE TO MEDIUM SANDS SILTY		
4048	PRE-Є	GRANITE, DIORITE		

It is improbable that the Cretaceous formation in Alter do Chão continues downstream and is directly connected at depth, with the Cretaceous in the "graben", because there seems to be a "sill" of crystalline basal complex, which is known as the Xingu arch, near the mouth of the Rio Xingu.

It is noteworthy that the Cretaceous sediments are coarser grained with faceted quartz and feldspathic sands (see Fig. 8 by Amaral).

According to Petri, in spite of the large amount of downsinking of the "graben", a truly marine transgressive facies seems to be limited to the sediments of the depth of—245 to 460 of Miocene age and mixed land and doubtful marine facies of Miocene age follows down to 1592 m. Amaral records intercalation of glauconitic beds in the sediments ranging in depths from—500 m to—1500 m, and is of the opinion that these beds are marine neritic origin. This may indicate that the rate of downsinking was nearly counterbalanced by the rate of filling with land sediments before and after the Miocene age.

B. Pleistocene, the age of entrenchment

a. Lack in sediments of glacial till, aeolian loess and volcanic ashes and supposed lighter load of the Amazon river during the Pleistocene

Extensive deposits of glacial till are found in the north-central plain of the United States, in those states of Dakota, Nebraska, Iowa, Missouri, Illinois and Wisconsin, etc.

They are also found in northern Europe: England, Denmark, Germany,

Poland and northern part of Ukraina, USSR.

Almost equally extensive are deposits of aeolian loess in such great plains as north China, Ukraina and northern Europe in a zone to the south of the area of the glacial till; and also the great "pampas" of Argentine.

Volcanic ashes are widely distributed on the plains of the islands surrounding the Pacific Ocean.

These consist primarily in decomposed, finely pulverized rock dust originally supplied by different agencies during the Pleistocene age. After once settled these sediments are easily subjected to reworking or redeposition by rivers. They are characterized as sediments supplied in large quantities at one time or in a short period of time into sedimentary basins, often overloading the contemporary river system and spreading flood waters over the bordering flood plains.

It is noteworthy that not one of these kinds of sediments, so common on large sedimentary plains of the world, is supplied to the extensive basin of the Amazon during the Pleistocene age.

The Amazon river, having 4 or 6 times as large amount of discharge as the Mississippi, is at present carrying a large amount of load in suspension. But the amount is much smaller per unit volume of water when compared with other large rivers in the world such as the Nile and Ganges and Mississippi (17, 33).

If the Amazon basin had a fairly large amount of precipitation, if not the same as the present one, during the Pleistocene age, it is inferred that the Amazon river system was not so heavily loaded as its contemporaries in the Pleistocene plains in other parts of the world.

b. Fluvial and beach sands—limited laterial extension and varying vertical thickness

Pleistocene sediments in the Amazon basin consist in sands, silt and kaolin clay. The sands are by far the predominant member.

On the scarp, about 80 m high above the river level, behind the town of Monte Alégre, there is a thick bed of loose sands overlying Tertiary clay and sandstone, the contact or the surface of unconformity being about 30 m above the river water.* Thus, the thickness of the sands is about 50 m. Within a few kilometers inland, they disappear and Paleozoic formations are exposed on the plateau of Monte Alégre dome.

On the vertical bluff at the town of Óbidos, the contact between Pleistocene sands and Tertiary clay and sandstone beds is well exposed. The thickness of the sands may be over 20 m and may be even considerably more in higher part of the town. To the north from Óbidos, on the right bank of Rio Curuçambá, at the crossing 12 km north of Óbidos along the highway, the contact of Pleistocene sands and Tertiary shale is exposed. The thickness of the sands is about 15 m and a few layers of pebbles are contained within the sands.

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* Mean water level of the Gurupatúba river at Monte Alégre is about 9m above sea level.

On the plateau to the north of Manàus*, a layer of sandy kaolin, about 8 m thick, covers the Tertiary.

At Nova Olinda the wellsite of the Petrobrás NO–1–AZ, near the confluence of the Rio Canuma with the Rio Madeira, Pleistocene sandy kaolin is only about 7 m thick, and is underlain by Tertiary mottled kaolinitic sandstone.

At the confluence of the main Amazon with the Rio Madeira is situated the Ilha da Trindade.

On this island, the wellsite of the Petrobrás TR–1–AZ, a layer of sands reaches down to the depth of 100 m, where it rests, with pebbles, on top of Barreiras formation. This appears to show the depth of the downward cutting of the channel of the main Amazon at this point.

At the wellsite of the Petrobrás AC–1–PA, at Alter do Chão, the hole strikes straight into the Tertiary sandstone and no Pleistocene sediments are recorded.

In Santarém**, loose sands, perhaps up to several meters thick, are distributed over gentle slopes over dissected and undulating hills of Tertiary sandy shale.

In the Territory of Amapá, gray to pure white quartz sands, up to more than 8 m thick, are observed filling depressions at various altitudes above sea level from less than 10 up to 100 m. They are sands apparently washed down into swampy low lands from the sandy top layer of lateritezed soil profile capping surrounding terrains. The white quartz sands in depressions are often deep black with organic matter. The low values of both pH and Eh of the environment due to the accumulation of organic matter in these depressions seem to be responsible for the segregation of kaolinite particles and perfect bleaching of the remaining sands.

These observations show that the Pleistocene sediments, dominantly quartz sands, are usually only a thin veneer over Tertiary and older rocks, but sometimes get quite thick locally as at Monte Alégre. That their thickness is not necessarily large on low lands is shown in the case of Nova Olinda.

It is remarkable that the areal distribution is also very limited considering the general flatness of vast Amazon basin (See accompanying geologic map, Mapa Geológica, DNPM, 1942 and Geologic Map, GSA, etc., 1/5.000,00, 1950, also Table 3).

Therefore, the Pleistocene sediments in the Amazon basin can hardly compare in their thickness and extent with their contemporaries in other great basins over the world, e. g. the sediments in the aeolin loess plain of the Argentine pampas ; the glacial drift plains of north America ; the aeolian loess plain in north China ; the aeolian loess and glacial drift plains of Ukraina, USSR and of countries in northern Europe.

The only Pleistocene sediments in the Amazon, which are significant in their thickness and extension seem to be found on Marajó Island. According

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* Mean water level of the Rio Negro at Manáus is about 19m above sea level.
** Mean water level of the Rio Amazon at Santarém is about 10m above sea level.

to the record of Cururú well, a test well for oil sunk by CNP*, grey silt met in the depth of 0 to 245 m is supposed to be of the Pleistocene age.

The silt is apparently partly bed load but partly suspension load of the main Amazon deposited on the Estuarine delta. Its greater thickness must be attributed to the continued crustal subsidence of the "graben" which was initiated perhaps in Cretaceous or even in earlier times.

The lower flatlands near Belém, Acará and Maranhão (10-20 m above sea level) are composed of Tertiary rocks but covered with a thin layer of quartz sands. These are possibly remnants of beach sands of Pleistocene lakes, estuaries, marginal swamps, and partly of even the open sea.

In short, the Pleistocene sediments in the Amazon are characterized by quartz sands. Their distribution is limited to a narrow belt along the main Amazon and the Atlantic coast. They are usually in a layer of blanket with variable but insignificant thickness (a few to 20 m). Only locally and abruptly does the thickness grow to over 50 m, as in Monte Alégre. The only exception is found on Marajó Island, where its vertical section gets as thick as 245 m and its material is grey silt, or is finer than the white sands common to the Pleistocene beds exposed on the land on both sides of the Amazon.

c. Channeling and planation due to alternate regrading of the Rio Amazon as the result of glacio-eustatic changes

Drowning of tributaries, evidence of regrading

The writer travelled on the Rio Trombetas in May, 1956 and again in Rios Trombetas and Tapajós in November-December, 1956, and also on the Rio Negro in June, 1957.

The Rio Tapajós, the Rios Tocantins and Xingu, show abruptly widened courses for 100-150 km before joining the main Amazon. The widening takes place over the courses where the rivers traverse the terrain of Tertiary formations.

The widened course of the Rio Tapajós within the Tertiary terrain has the average width of 15 km, and a length of 120 km from Aveiro to Santarém.

The Rio Negro is in a similar situation. Along its lower stretch to the northwest of Manaus, it shows a gradual widening of its channel as it passes the terrain of the Paleozoic sandstone into that of the softer Tertiary formation.

It is probable that all of these disproportionately wide courses of these great tributaries are drowned valleys. During the glacial ages the sea level was lowered for a few scores to possibly up to 100 m at its maximum, below where it is now. The Rio Amazon and other potent tributaries cut their channels down deeper according to the lowering of sea level and the channel of the Amazon. During the interglacial ages, the ice melted and water returned to the ocean to cause the level to rise again. The main Amazon deposits more load than the tributaries do (see 1, a: difference in height and width of

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* Conselho Nacional do Petróleo.

levees). Those tributaries which could not keep up with the main Amazon in re-filling the channels became drowned, resulting in the estuary shaped "lakes".

The lower courses of the Rios Tapajós, etc. are completely drowned. The width of the "lake" represents approximately that of the former meander belt cut down during the glacial ages. The series of steep cliffs of Tertiary formations on both sides of the "lake" of the Rio Tapajós are remnants of spurs truncated by its meandering stream during the Pleistocene.

The Rios Tapajós, etc. are completely drowned, while the Rio Trombetas is half drowned. As has been described in the Article 1, the natural levees of the Trombetas are built of kaolin clay. The mass of kaolinite is consistent in spite of its softness and built into steep walled, smoothly curved levees separating the main river course from large and small lakes behind them. The Trombetas, being from 400 to 800 m wide, displays unusually elegant form of open meandering with the kaolinite levees covered thickly with luxuriant gallery forests. In its lower reaches, near Oriximiná*, i. e. the floodplain of the main Amazon, these levees become only two rows of parallel dykes whose height becomes so reduced that they are submerged at places even under the low water of the lakes.

During the flood seasons, however, the stream of the river seems to run through its channel between these parallel dykes with higher velocity and competency, gradually building the low dykes into higher levees. So, the prestige of the river seems to be not yet entirely lost.

In the upper reaches, the kaolin clay levees are found to be in the form of bars built across the mouth of valleys emptying into the Trombetas. Thus, the refilling by the Amazon of its channel since the Pleistocene, has half drowned the Trombetas, and, the refilling by the Trombetas of its channel is, in turn, drowning its sub-tributaries.

Alternate entrenchment and planation

It is supposed by some authorities that the climate during the Pleistocene age was wetter during glacial ages and drier during interglacial ages. If this was the case it naturally follows that the Amazon river system had a larger amount of discharge during glacial ages than during interglacial ages.

As has been stated in the previous chapters, we have no glacial drifts, aeolian loess nor volcanic ashes in the Amazon valley, which are common sediments characterized by their rapid supply to and hence overloading of Pliestocene rivers in orther great basins of the world. The Tertiary formations consisting of kaolinitic sediments, are soft to cutting but do not yield large quantity of materials for sediments.

So, it appears that the Amazon river system had a very light load for its increased amount of discharge when their course were regraded more steeply due to the lowering of sea level.

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* Mean river water level is about 15m above sea level.

The maximum lowering of sea level is in the Wisconsin (Würm) glaciation and is supposed to have reached −100 m or over.

Under these circumstances, a very vigorous trenching of the channels into bed rock with increased competency of the rivers is natural. Especially deep valleys were cut into the soft materials of Tertiary formations.

During the interglacial ages, it is generally known that sea level was restored and rose higher than is now. In fact, if all the ice now at the polar regions were released by melting and returned to the oceans, the present sea level would rise, according to different authors, from about 40 to 60 m. With the rise of sea level approaching this amount or even a fraction of this amount, the Amazon river system must be regraded substancially. Extensive lakes and estuaries developed along the lower reaches and maritime regions. Sands of older Pleistocene (Coswine series) age are widely distributed along the coast of French Guiana on flatlands with the altitudes of 25-50 m above the sea. Blue clay of later Pleistocene (Demerara) series occupy the flat coastal plain with the altitudes usually less than 25 m above the sea (9).

The competency of a river in the upper course was materially decreased due to a flatter gradient and supposed smaller precipitation. Under these circumstances, sediments were not transported far downstream, but left in valleys and along the shores of wiedened lakes and estuaries, filling in depressions entrenched during previous glacial ages.

Thus, the glacial ages are those of trenching or channelling and the interglacial ages are those of planation. Judging from our observations in Rios Tapajós, Trombetas, Uatumão, Paraná do Ramos and Rio Maués, Rio Negro and its small tributaries near Manaus, etc., the glacio-eustatic changes had a very important effect upon the regrading of the Amazon river system. The effect of the regrading proves to be particularly manifest in the Amazon river system on account of the highly increased competency of rivers due to lack in contemporary sediments of glacial drifts, loess and valcanic ashes on the one hand, and of soft material of Tertiary formations amenable to cutting by streams on the other.

There were four glacial ages and three interglacial ages as follows:

Glacial ages:	Interglacial ages:
Wisconsin (Wuerm)	
Illinoian (Riss)	Sangamon
Kansan (Mindel)	Yarmouth
Nebraskan (Guenz)	Aftonian

Topographic maps of large enough scale with detailed contours are not available in the Amazon. It is not possible to identify the effect of change in individual age with the terraces of different altitudes. According to our observations around Ôbidos and Alter do Chão (near Santarém), however, effects of pre-Sangamon and Sangamon planation and pre-Wisconsin and Wisconsin trenching seem to be detected. Planes of planation, P_1 and P_3; and valleyes of trenching, P_2 and P_4 are shown on an idealized cross section in Fig. 7.

The Plane of Pleistocene planation, P3, is represented by rather extensive

coastal and river terraces in Bragança-Belém-Acará, etc. Similar fluvial ter-
races are widely developed in such areas as Santarém, Alenquer, Urucará,
Parintins, Barreirinha and Maués. The well-known grazing land of the Rio
Autaz Açu (near the confluence of the Rios Amazon and Madeira) appears to
belong to this category, too. When these terraces are only about 10 m or less
high above the flood water, they are locally known as "terra baixo", and
make favorable pastures during floods, when "várzeas" are almost entirely
beneath the water.

It takes, however, years of field work and topographical surveying to
analyse the effects of the glacio-eustatic changes in more detail.

Net effect of entrenchment

Even our limited observations show that flatland with Pleistocene sands
is comparatively limited in area (for the vastness of the Amazon basin), while
steep sloped valleys cutting into the Tertiary and older table land are a very
conspicuous and widespread feature.

Thus, the net effect of glacio-eustatic changes during the Pleistocene age
is entrenchment or channelling.

Submerged landscape along the course of the Amazon has been noticed by
geographers and appropriately called the "Amazon rias" (27).

d. Crustal subsidence.

It has been stated in previous chapters that the grey silt bed met in the
test well for oil at Cururú on Marajó Island at the depths of 0–245 m is as-
signed to the Pleistocene in age. Apparently no marine fossils are found in the
bed. So, it may be of fresh water origin.

If the crust remained static through the Pleistocene, then the maximum
thickness of sediments laid under deltaic conditions upon the shelf (not upon
continental slope off the shelf edge) during the restoration of the sea level,
should not exceed the depth of maximum lowering of sea level or about 100
m plus perhaps a few scores of meters which represent the depth of the
lowest bottom of the channel reached at that time.

Therefore, if the grey silt bed (245 m thick) was formed under the enviro-
ment of an estuarine delta, it is inferred that the difference in thickness:
roughly around 100 m at least may be accounted for by the crustal subsidence.

Near the edge of the continental shelf off the Mississippi delta, USA, a
detailed study has disclosed very interesting succession of thick sediments
deposited on the rapidly sinking crust. It shows cycles of deposition during
the Pleistocene age which may correspond to glacial and interglacial stages
(1).

At this locality off the Mississippi delta, the crustal subsidence amounted
to several hundred meters during the Pleistocene. The sediments are marine
and brackish.

Whereas, in Marajó Island the sediments appear to be fresh water. This
may not be unnatural if there was a crustal subsidence of the above magni-

Table 2.   Depth and thickness of Pleistocene sediments
off the Mississippi delta

Depth in core (m)	Lithology	Depth of water of deposition (m)	Cycles	Age
450			Several cycles	Wisconsin (glacial) & Sangamon (Interglacial)
635	sands and gray clay	near shore	Regression	Illinoian (glacial)
730	gray shale	180	Transgression	Yarmouth (Interglacial)
930	sandy shale	60 upper neritic	Regression	Kansan (glacial)
1100	gray shale	180	Transgression	Aftonian (Interglacial)

The base of Nebraskan is inferred to be about 1270 m:

tude (100 m ±) on Marajó Island as the consequence of continued tendency in downsinking of a "graben" since possibly Cretaceous age. The absence, at the mouth of the Amazon, of such a delta as comparable with that of the Paraiba (16) or of the Mississippi, is perhaps due to the fineness of sediments as well as to the strong tidal currents there.

For the upper stretch of the Amazon river, upward of Santarém, however, the effect of crustal subsidence is not so clear. According to the Geologic Maps (DNPM and GSA), the areal extent of the Quaternary sediments is very limited and far from following the ever widening extension of the Barreiras formation as it approaches the Colombian and Peruvian boundaries.

The thickness of the Quaternary sediments is also very limited. At Nova Olinda, situated at about the central part of the Quaternary area as shown on the above maps, the Quaternary sediments seem to be only several meters thick. On the banks of the Rio Amazon at Manaus, Itacoatiara, Jurutí, Óbidos, opposite Alenquer, Santarém and Monte Alégre, the Tertiary Barreiras formation is well exposed. It underlies the pleistocene sands with the contact exposed at varying height above the river water.

The extremely low altitudes of the floodplain and the abundance of lakes along the course between Itacoatiara-Oriximiná may be attributed to a slight submergence. The frequent Yazoo type and, at the same time half-drowned tributaries may also be its outcome.

Steeper gradient, and more rapid flow, of the main Amazon between Manàus—Itacoatiara, and Jurutí—Santarém and comparatively few lakes and narrow floodplains along these reaches, suggest that these are zones of positive elements in the crust, that is, slightly upheaving or at least, less downsinking zones.

When compared with these zones, the earlier mentioned reach between Itacoatiara-Oriximiná may represent a negative, that is, a slightly downsinking or at least, less upheaving zone.

It attracts our attention that a few horsts and grabens, trending in more or less NE–SW direction, are inferred by CNP along the above course of the Amazon. This is based upon the interpretation of earlier seismic work carried on by CNP (12).

Prof. H. O. Sternberg is of the opinion that the drowning of the tributaries is to be attributed not only to the glacio-eustatic changes but also to the crustal subsidence (38). His opinion is based upon rectilinear faults, which he claims to be followed by many rivers, tributaries and lakes, and isostatic consideration.

3. Origin of "terras firmes" and "várzeas" in the lower Amazon basin

a. "Terras firmes" and "várzeas"

The conceptions of the "terras firmes" and "várzeas" by geographers in Brazil are as follows:

"Terras firmes":—

"terrains of the Amazon Plain that are not flooded by the water of rivers and tides" (13).

"... higher land formed by the low Tertiary plateau, which constitutes the floor of the Amazon Basin" (34).

"The vast sedimentary area—the largest in the world—commonly known as the Amazon Plain, is as was observed sometime ago by Denis (Pierre-, 1927), really a low Tertiary Plateau, most of which presents a subdued relief of mesas, ridges, and table-lands" (35).

"Várzeas":—

"The lowest level of the Amazon Basin is made up of the Alluvial plain of the Amazon and of the lower courses of its tributaries. These lowlands are of recent formation and are made up of an accumulation of clays and sands, being flooded by high water in the interior of the continent, and by high tides along the coast and in the islands region; thus, the floodplain includes the fluvial and coastal "várzeas" (36).

"Idealized cross-section of the Amazon floodplain, showing the principal elements of its drainage, relief, and vegetation" (37) (illustration not shown here).

It seems that, according to the conventional usage among people in Amazon, a várzea is annually flooded land, a terra firme is non-flooded land and the Tertiary plateau with the altitudes of about 100 m is "planalto" or "serras".

The present writer follow, in this paper, the conception by the above geographers.

b. Plateaus, mountains, and undulating hills and flatlands on terras firmes

Over the central part of Brazil along the divides between the Amazon valley system and Rios São Francisco and Paraná, there are extensive plateaus capped with flat-lying red sandstone of Cretaceous age. The plateaus, when viewed from an aeroplane, are dissected along their edges by steep-walled ravines into series of discontinuous polygons. The altitude of the flat plain of the plateaus above sea level is generally only 400–600 m.

As these plateaus extend northeastward along the Rios Tocantins and Araguaia, their altitude is gradually decreased down to 200 m.   On the north-western extension over the divide in Mato Grosso into the Territory of Rondonia, the plateau of the Cretaceous sandstone keeps more or less constant altitude of about 400 m.

The flat-lying Cretaceous sandstone beds capping these high plateaus are, as has been stated, evidently remnants of once far more extensive continental sediments, whose accumulation resulted in the planation of the interior during the Cretaceous age.   It is not clear, however, if these sandstone beds extended and covered the whole central part of the basin along the present main Amazon river.

In the central part of the basin along the present Amazon river, is another plateau, equally extensive but built of Tertiary sediments.   The flat surface of this plateau is 60-100 m or a little more along the lower Tapajós, around Óbidos and Oriximiná and also Manaus.   It seldom attains altitudes of 200 m or over, except in the Territory of Acre.

Almost only exception, and a conspicuous one, is the Serra do Paranaquara near Almeirim.   It attains the height of 350 m above the sea, with a perfectly flat top with horizontal beds.   These beds are considered as Tertiary by C. F. Hartt and also by Petrobrás geologists who made a reconnaissance flight over this Serra recently.   In the writer's opinion these beds may be somewhat older than the Barreiras formation forming the lower plateau just referred to above.

This lower plateau of Tertiary sediments represents, as has been stated before, another age of planation in the interior due to continental sedimentation.   This Tertiary plateau or plain is known as the "Amazon Plain" or the "floor of the Amazon basin".

There are intermediate plateau regions, also very extensive, between the above Cretaceous and Tertiary plateaus.   These are the terrain composed mainly of the crystalline basement rocks.   The altitude of these plateau regions is 200-400 m above the sea.   The flat surface is supposed to have been built during the intermediate ages, mainly in early Tertiary ages (T_1 —T_n in Fig. 7).

Around these plateaus of crystalline basement rocks, there are terrains of steep sided mountains and undulating hills showing the effect of continued dissection—entrenching and planation—, e. g.   Serra do Navio, Vila Nova in the Territory of Amapá.

Near the mouth of the Amazon and in the maritime region the Tertiary sediments as well as those of the Cretaceous tend to show a tilted surface of plains of flat lands gradually descending toward the Amazon and the Atlantic ocean, e. g.   Amapá, Bragança region of Pará and Maranhão.

One thing that particularly attracts our attention is the mode of dissection of these plateaus and flat lands.

The Cretaceous plateaus in the interior show clear cut edges with precipitous slopes which are characteristic to arid weathering.   The landscape

reminds one of those in arid plateau regions in the southwestern part of U. S. A., with mesas and often fantastic pinnacles with imposing rocky cliffs.

The Tertiary plateaus and flat lands are cut by numerous small, but conspicuously steep sided gullies, e. g. along the lower Tapajós, around Manáus, etc. The steepness owes its origin to the compactness of the Tertiary sand beds cemented with kaolinite, and also to the effect of dominant entrenchment during the Pleistocene age (see article 2B).

The relatively small areas of the Tertiary plateaus of very low altitudes, e. g. 25 m around Santarém and 10-20 m near Belém and also in the maritime regions, may represent the limited effect of planation during recent interglacial stages (p_1, p_3 Fig. 7).

The crystalline basement plateaus merge into mountains and undulating hills. Monutains are often quite steep sided, e. g. Serra do Navio, Amapá; this is due to the active down cutting by high and heavy rainfall. The mountains gradually give way to undulating hills in the direction toward the Tertiary plateaus, e. g., along Rio Tapajós. These hills are subjected to the process of planation during the younger Tertiary age as well as to the process of dissection which continued from preceding ages. The terrain of the Paleozoic formations, that is their outcrop, lies in these undulating hills, fringing the low plateau of Tertiary formations along the lower Amazon river.

c. Natural levees, fluvial lakes, swamps on the flood plains or várzeas

The natural levees are found all along the main Amazon and its tributaries, except where the streams are scouring their channels directly cut in the cliff of Pleistocene and Tertiary, or older formations. The levees along the main Amazon keep a more or less constant height of 3-4 m, except on the concave banks at bends, etc., where they attain the height of 5 m or more locally. Behind the levees are large and small lakes, such as the Lago Grande (Monte Alégre), Lago do Itandeua (Curuá), Lago Grande do Curuai (opposite Óbidos), Lago do Sapucaia (Oriximiná), Lago do Saracá (Itacoatiara).

These lakes are from 30 to 100 km long with varying depths reaching occasionally as great as 30 m. The outline of these lakes are extremely irregular. In fact, these lakes consist of series of creeks or paranás-some of them active but most of them abandoned—and swamps and dendritic shaped drowned valleys of tributaries.

The natural levees have steep bluffs facing the main stream but very gentle slopes with gradients from fractions of one to a few meters in 100 m- toward the lakes. These lakes are connected with the main Amazon by rivers (rios and igarapés).

The tributaries usually empty into these lakes and then join the main Amazon by rivers or rios and igarapés (which bear different name from the tributaries) thus showing confluences of a Yazoo type.

The natural levees of the tributaries, as they empty into the lakes, gradully lower and flatten down until finally get submerged even at low water level (Lago Grande, Monte Alégre, etc.). Along the rivers, connecting the lake with the main Amazon, levees resume a height of about 3 m above the low

water (Rio Gurupatúba, Monte Alégre, etc.).

Along the lower course of the tributaries, conditions similar to the main Amazon are found regarding the relation of natural levees and lakes, only the lakes are much smaller.

During the flood season of the main Amazon and also of the tributaries, the rivers with rising water level gradually inundate and drown most of levees as well as the lakes. At some high floods, even the higher levees such as those on the concave bank at bends, etc., and also upstream of tributaries are flooded for a few weeks or at least for a few days.

On those low levees and flat lake bottoms which are inundated for over 6 or 7 months annually, only grass and occassional trees grow.

Higher levees and the shore of the lakes which are flooded for 5 months or less annually develop a forest cover, which is called an "igapó forest". when the trees form narrow rows on natural levees it is called a "gallery forest".

Farmers usually select plots on the levees at a concave bank for their houses, because they are molested by the floods to a less degree on account of a slightly higher elevation here than at other parts of the levees and also command a better view both upstream and downstream.

Along the main Amazon and its paranás, store-keepers (vendas) and jute planters (juteiros) prefer these higher levees, too. But they have to build their houses on floors raised above the ground by 0.5 to over 1.5 m.

The low levees and adjacent flat lake bottom in the Lago Grande (Monte Alégre) become dry, giving grazing land for cattle during the dry seasons. Houses are built along low levees for the ranchers and their families for temporary use. When the flood season comes back the cattle are transported to the safe ground of the "terra firme"—both natural grassland on the Ereré dome and cultivated grassland near the town. Houses along the levee which have been evacuated by the ranchers are covered by water reaching as high as a meter above the eaves during a flood.

d. Limited—or almost non-existence of "elevated" floodplains

The areal extension of the Pleistocene sediments is very limited in the Amazon basin for its vast size (see Geologic Map, DNPM and GSA, etc.). Erosion and entrenchment rather than deposition and planation during the Pleistocene age are supposed to be responsible for this limited extension (see Chapter 2B).

As has been stated in the chapter 2B, such sediments as glacial tills, aeolian loess and volcanic ashes are not found in the Amazon. Those sediments found on the flatlands along the main Amazon are limited amount of sands mixed with different amount of kaolinite. And the down cutting or entrenchment has been so active that those flatlands with Pleistocene on top get dissected to such depths as to expose the underlying Tertiary formations along low but steep bluffs (Monte Alégre, Óbidos, Manáus, Nova Olinda, etc.).

After the most vigorous entrenchment during, perhaps, the Wisconsin (Wuerm) glacial stage, the Amazon river has come back to deposit sediments

as its stream gets slackened by regrading. But, so far, the more the main Amazon filled its own channel, the more it drowned its tributaries, ever extending the " backwater " in flooded areas upstream along their courses.

Neither loess nor volcanic ashes, if not glacial tills, is thought to have been supplied during the Pleistocene age in Amazon. If they had been supplied in large enough quantities to overload the river system, they would have covered at least the lower part of the Tertiary plateau and formed very gently undulating plains perhaps with several river terraces separating it from the river channels. This would have provided easily accessible—for communication and irrigation—but no longer flooded, low plains suitable for agriculture and other activities.

The writer has visited the world's great agricultural lands such as North China (many times up to 1945), northern states in USA (in 1926–1928), Ukraina, USSR (in 1937) and Germany, Netherland, etc (1929 and 1937). He has not visited the great pampas of Argentina. These four great sedimentary basins all have the Pleistocene sediments of either one or more of glacial tills, loess, volcanic ashes.

The topographic accessibility of land in the terrains of these deposits seems to be one of the favorable factors for its use for agriculture and other activities.

The Amazon basin, in spite of its general flatness of the land, has a comparatively limited area of this kind of plains which are low but no longer flooded, that is, " elevated " floodplains.

Very extensive plateaus on different levels with minor zones of mountains and undulating hills intervening or fringing them, make a unique contrast with plains which are very low and inundated perennially or for a longer or shorter time of the year.

The lower plateau consisting in the Tertiary sediments is known as the " terras firmes " and the floodplains as the " Várzeas ".

4.   Rock weathering and soil genesis on terras firmes,
plateaus, etc.

A.   Petrographic control of weathered products

The approximate porportion of the areal extension of each one of the main geological formations in the Amazon is estimated as follows (based on the Goelogic Map—G. S. A., etc., 1950):

a.   Crystalline basement rocks of the pre-Cambrian age
  Distribution:
    So-called Guiana shield (Territory of Amapá to Territory of Rio Branco)
    So-called Central Brazilian shield (Pará-Amazonas -Mato Grosso-Rondonia)
    Mato Grosso-Bolivian boundary
    Rios Araguaia-Tocantins area (Goiás-Mato Grosso)
    Rio Gurupi area (Maranhão-Pará)
  Rock types:

Table 3. Areas of different geological formations in the Amazon*

Geologic formation:		Approximate area (km²)	Percentage in whole Amazon
Pre-Cambrian	Early	1,770,000	35 %
	Late	100,000	2
Paleozoic.		280,000	5.5
Triassic		150,000	3
Cretaceous		710,000	14
Tertiary		1,670,000	33
Quaternary	Diluvium & Alluvium	250,000	5
	River & Lake water	100,000	2
Diabase		25,000	0.5
Total		5,055,000	100

* Approximate areas estimated by the writer on the Geologic Map of South America (1/5,000,000), Geol Soc. Am., et al., 1950.

According to Moreira (19), areas and population of different states of the Amazon under the jurisdiction of SPVEA (Superintendência do Plano de Valorização Econômica da Amazonia) are as follows:

No.	Unidades	Area (km²)	População-1.7.1950
1	Amazonas	1,595,818	514,099
2	Pará	1,216,726	1,123,273
3	Maranhão	283,961	1,260,566
4	Goiás	326,197	242,768
5	Mato-Grosso	875,720	201,600
6	Acre	153,170	114,755
7	Guaporé	254,163	36,935
8	Rio Branco	214,316	18,116
9	Amapá	137,419	37,477
	Total	5,057,490	3,549,589

Migmatite gneiss, granite, syenite, charnockite (according to A. de La Rue), diorite, mylonite, quartzite, mica shist, amphibolite, etc.

The writer observed these rocks and weathered products in the Amapá (along Rios Oiapoque, Araguari, Vila Nova) and Gurupi (along Rio Maracaçumé) areas, and also along Rios Erepecurú and Trombetas.

They form typical laterite profiles:

Complete profile, over 8 m thick   (Port Platon, Amapá
                                     (Serra do Navio, „

Incomplete profile, 6 m±   (Ferreira Gomes, „
                                     (Oiapoque,   „

Both complete and incomplete laterite profiles consist in massive, mottled kaolinite with quartz grains, covered with a layer of sandy kaolin 0.2-1.2 m thick.

In a complete profile, the top layer is very sandy (sand=70%±); has limonite concretions (so-called "laterite concretions") and the contact with the underlying kaolinite is sharp.

In an incomplete profile, the top layer is less sandy (sand=50-60%), has almost no limonite concretions, but is uniformly orange red in color, showing

a gradual transition into the underlying light colored kaolinite. In the Territory of Amapá, huge granite boulders are occasionally seen exposed in forests and grasslands, which look like a camel's back from the distance. Their backs are sometimes rounded but at other times form thin and sharp edges. On their sides, rows of ridges and grooves are carved out in such a manner as to remind one of limestone blocks of solution relics on a "karst" plateau.

In Oiapoque a piece of bauxite, containing a considerable amount of quartz grains, still retained the banded structure of a gneiss.

These observations show how active the agencies of weathering are under a tropical climate.

In fact, the large manganese deposit in Serra do Navioa in a very irregular bed or blanket form ranging in altitudes of 200 m–270 m above sea level, is supposed to be an old crust of laterite weathering. The phosphatic bauxite deposits with kaolinite layers of the Trauira Island, etc. are over 34 m thick and easily rank among the thickest of known laterite profiles over the world. These laterite profiles with a thick crust of economically useful minerals are among the weathered products of the pre-Cambrian rocks.

The process of lateritization in these thick profiles possibly dates as far back as the Cretaceous-Eocene, which is one of the greatest ages of lateritization over the world in the past.

Those laterite profiles covering the mountain slopes of pre-Cambrian basement rocks are possibly of Pleistocene origin. While, among those covering the surface of plateau, there may possibly be older profiles which are more promising for bauxite, manganese and iron ores, etc. As the mother rock for bauxite, syenite is better because it has no quartz. Nepheline syenite or phonolite, as in the great bauxite deposit in Poços de Caldas, in the state of Minas Gerais, is the best because of unusual amenability of nepheline to weathering process.

Among the common rock forming minerals those minerals which crystallize out from magma earlier, or under higher temperature and pressure, are more easily decomposed by weathering than those that crystallize out later. So, olivines, pyroxenes and labradorite, etc. get decomposed sooner than micas and orthoclase. The less the degree of polymerization of Si-O tetrahedron in the mafic series and the more the substitution of Al for Si in the feldspar series, the more easily the minerals break down.

Clay minerals are highly stable under the weathering condition. They have mica type- or sheet structure with high degree of polymerization and are also high in Al.

Quartz is the last of common minerals to be decomposed on the land surface.

Generally speaking, the igneous and metamorphic rocks of the basement complex are more easily susceptible to weathering processes than are sedimentary rocks of later formations.

b. Slightly metamorphosed sediments of the Paleozoic age, characterized with illitic clay mineral

Trombetas formation (Silurian):

Indurated slabby sandstone and laminated silicified shale.

Maicurú formation (Devonian):

White sandstone, sometimes massive and sometimes thickly slabby and case-hardened, weathers into loose sands with limited amount of clay. Color light orange and brilliant reddish orange to a depth over 1 m.   Test pits made under slope forests, Cachoeira Porteira of Rio Trombetas and Tronco of Rio Erepecurú.

Curuá formation (Devonian):

Black shale, laminated illitic shale.   The laminated illitic shale, is soft but tough, and according to X-ray test with Norelco by Dr. Távora, D. N. P. M., consists in quartz and illite.   Upon analysis it gives 2.5% K_2O. So, the content of illite may be 50% or even less.   This appears to weather into grayish yellow soil, but no test pits were sunk by the writer. It may be possible, however, that the potash content of this shale accounts for the comparatively large K_2O content of soils in Inglês de Souza, Monte Aléger (Dr. João Pedro Filho).

At Cachoeira Santo Antônio, Rio Jari, Amapá, red shale supposed to be of the Devonian age weathers into yellow kaolinitic clay (under forest). But a large amount of undecomposed pebbles and blocks are contained throughout the profile.   This shows the stability of a sedimentary rock, consisting in illite (?), kaolinite and hematite, under the weathering conditions.   That is because the silicate minerals are already hydrous aluminum silicates of mica-type layered minerals, i. e., clay minerals, and iron is in the highly oxidized state (ferric).   Illite ultimately gives way to kaolinite, but the only possible change that hematite undergoes is reduction when the Eh is lowered under forest.

Monte Alégre formation (Lower Carboniferous):

White, medium to coarse quartz sandstone, cross-bedded.

Itaibúba formation (Upper Carboniferous):

Purple and green shale, limestone.   Appears to give part of the fertile soils in colonies around Monte Alégre.

Nova Olinda formation (Upper Carboniferous, 1200m± and contains evaporite: anhydrite and rock salt 489–640 m, in the center of the basin):

Red and green shales are exposed in Curuá (Alenquer) and Erepecuru-Cuminá (Oriximiná) areas.

c. Non-metamorphosed sediments of the Cretaceous age, characterized with montmorillonitic (?) clay mineral

Itapecurú formation (Upper Cretaceous, may be partly Tertiary, 120 m):

Occurs in the State of Maranhão: Light red sandy shale, red and green shale.

On flat top of hills they weather into deep sandy soil.   On slopes they are subject to mass-wasting by slides and flows.   This susceptibility to mass-wasting is probably due to the presence of montmorillonite derived from arkosic and tuffaceous sediments.   There may be some illite that

possibly supplies K_2O for babaçu trees which flourish in this region and are said to require K_2O.

According to Amaral, Cretaceous sediments met with in the depths greater than—2000 m, in test wells for oil on and near Marajó Island, are characterized by faceted quartz and feldspathic sands in contrast against the overlying Tertiary sediments which are possibly correlated to the Barreiras formation (See Fig. 8).

It appears to be almost certain that the Cretaceous sediments, which are generally arkosic, are charged with appreciable amount of volcanic materials.

It seems that these Cretaceous sediments give soils with higher content of bases than the sediments of the Tertiary Barreiras formation.

d. Non-metamorphosed sediments of the Tertiary age, characterized with kaolinitic mineral

Barreiras formation (Miocene, 0–600 m):

Observed by the writer in Manaus, Oriximiná, Óbidos, Santarém, Aveiro, Monte Alégre, Amapá.

Light reddish purple and white sandstone cemented with kaolinite and kaolinitic shale, and mottled massive kaolinite. This usually gives sandy surface soil and even white sands along the beach of lakes.

The very thick, clayey surface soil, yellow in color, under the flat forest lands, such as were observed by the writer in Manaus and Itacoatiara, and also by Mr. Pitt to the east of Santarém, seems to be the product of weathering of kaolinitic shale members intercalated among the Barreiras formation and nearly free from quartz.

The sediments are predominantly kaolinitic. When these sediments weather they give way to sandy kaolin and finally to quartz sands.

An example of the analysis of an argillite of the Barreiars series, from the cliff of the Rio Tapajós at Alter do Chão is shown by Amaral (3):

Loss on Ignition	11. 4%
SiO_2	62. 1
Fe_2O_3	2. 8
Al_2O_3	21. 0
TiO_2	1. 1
Mn	None
CaO	None
Mgo	0. 4
Total	99. 7
Na_2O and K_2O	0. 3 by difference

According to Amaral, this argillite consists in "aggregates of heterogeneous mass of unidentifiable clayey-micaceous minerals, possibly derived from volcanic glass".

In the present writer's opinion, the alkalies and alkaline earth appear to be a little too low for a clayey material of volcanic glass origin. Such clayey materials usually contain from a few to several per cent of alkalies and alka-

line earth.   Judging both from this analysis and from what he has seen in Belterra, about 14 km to the south of Alter do Chão, this material seems to consist mainly in quartz silt, kaolinite and possibly minor amount of clay mineral of "hydromica" type.

It is indeed quite possible that there exist some amount of "chalcedonic" quartz silt and "hydro-mica" type clay minerals which are derived from the decomposition of feldspathic minerals or even from volcanic glass in the Tertiary sediments along Rio Tapajós.

At Aveiro, about 90 km upstream of Rio Tapajós, the writer found occasional pieces of volcanic rocks among the pebbles of the Tertiary conglomerate. It is possible that the Cretaceous beds, occupying a large area in the Alto Tapajós basin, contains volcanic rocks, as their counterparts in the State of Maranhão do, and these beds supplied volcanic materials to the sediments of the Barreiras formation along the Baixo-Tapajós.

If this is the case, the situation is quite similar to that of the Tertiary Pirabas formation which appears to have obtained their materials from the neighboring Cretaceous formations in the States of Maranhão and Pará.

Pirabas formation (Miocene):

Occurs in Bragança region, Pará, and in Maranhão.

Generally speaking, the materials of the Tertiary formations are strikingly kaolinitic, but locally they are mixed with volcanic materials derived from neighboring Cretaceous formations.   Whether or not the tuffs and their derivatives—alkali bentonites, etc. supplied by the contemporary Andean volcanism (Miocene) are contained in the Barreiras formation in the Baixo-Amazonas is not clear at present.

e.   Fluvial and beach sediments of the Pleistocene age

As has been stated in the Chapter 2Bb depressions and gullies are filled with gray and white sands, which are thought to have been shifted down from the top sandy layer of lateritic soil and also washed out directly in the weathering basement rocks.

These sands are sometimes almost free from clay and at other times contain a considerable amount of clay, perhaps up to 40% or even more.

Sands free from clay are often found in grasslands in Oiapoque and along the highway from Macapá to the town of Amapá.

Sands containing clay have been observed by the writer on the plateau of Óbidos and Manáus.   These are usually covered with forests.

Sands on the plateau of Monte Alégre are intermediate in clay content, and covered with sparse brushes and low trees—campo coberto.

The surface of these sands is usually grayish brown and gradually turns into yellow, brown or orange red at a depth of within 0.5 to 1.5 m.

Small pellets of MnO_2 were observed in a section in Coroatá, Maranhão, under a cleared forest.

f.   Diabase

It is well known that the Paraná trap (basalt and diabase) in the States of São Paulo, Paraná, etc. is the mother rock of the terra roxa or a fluffy,

red, unsually fertile soil in the south.

Diabase is fairly widely developed in the Amazon. It is usually in the form of intrusive sheets or dykes into Paleozoic formations and pre-Cambrian basement.

The vertical thickness of these sheets are known, from bore holes, to be a few to even several hundred meters.

In the State of Maranhão, however, extrusive basalt is known to the northwest of Grajau, whose age is thought to be Jura-Cretaceous by Campbell (8), but Triassic by other authors (21).

Diabase stands weathering in river water and often forms cachoeiras or rapids and falls. But it usually weathers easily into red soil on the land surface.

In an old laterite profile near the airport, Oiapoque, a crust of very ferruginous bauxite, about 7 m thick, covers a diabase. At the Cachoeira Santo Antônio, Rio Jari and Fordlandia, Rio Tapajós, red soil is found on top. At the Petrobrás wellsite on the Rio Cupari, the diabase weathers into a gray and purplish mottled mass and then into yellow soil.

Red soil appears, however, to be by far the commonest type. According to a pedologist from Campinas Agricultural Experiment Station, São Paulo, this is said to be almost like the genuine terra roxa in the south, only much more compact and sticky. The section in a test pit at Cachoeira Santo Antônio, about 1.5 m deep, showed a massive, compact mass of deep reddish brown color.

Readiness of diabese to get weathered under surface condition is due to the susceptibility of mafic minerals and basic feldspars, such as labradorite, etc., to surface weathering conditions with low pH and high Eh, with a larger supply of O_2. The river water is more or less neutral, and is less destructive against diabase.

B. Lateritization—Climatic and physiographic control

a. *Laterite profile and soil profile*

A very close parallelism of paragenetic zones of clay minerals is observed between profiles of a complete or mature laterite and of an alunite ($K_2 Al_6 (OH)_{12} (SO_4)_4$) deposit. Zonal arrangement of minerals with different types of crystal lattice corresponds exactly with each other (30).

These clay minerals are sensitively in equilibrium with the medium with which they are in contact. Owing to the time lag in reaction, however, the perfect profile is not always established. But, given sufficient time, the equilibrium is nearly eslablished and the profile grows matured and completed.

Thus, the profile of an alunite deposit or laterite (A′, B′, C′) is as much a profile as is the soil profile of the pedologists (A, B, C) (Table 4).

A laterite profile with only B′$_2$+C′ is incomplete while one with B′$_1$+B′$_2$+ C′ is complete. The zone A′ or the sandy top layer represents the procuct of a retrogressive stage or so-called tropical podsolization in the Amazon, as understood by the writer.

The word "laterite" by common usage often indicates "lateritic concretions" which are ususlly limonite concretions. But "laterite profile" or

Table 4. Zonal arrangement of residual clays with reference to
ground water table and basement rock

Alunite deposit:	Zone of profile:	Type of crystal lattice:	Laterite:	Fossil soil symbols:
Chalcedonic quartz	$SiO_{4/2}$	t	Quartz sand	A'
High ground water table				
Alunite and diaspore	K, Al-sulphate $Fe(OH)_3$ $Al(OH)_3$	o	Laterite concretions	B'$_1$
Low ground water table				
Dickite	$Al_2Si_2O_5(OH)_4$	to	Mottled kaolinite	B'$_2$
Pyrophyllite and sericite	$Al_2Si_4O_{10}(OH)_2$	tot	Illite, chlorite, nontronite, montmorillonite	C'
Basement rock				

A': zone of extreme leaching under perennially acid condition
B'$_1$ & B'$_2$: zone of leaching of alkalies, alkaline earths, but zone of enrichment
    of Fe- and Al-hydroxides under intermittently acid and neutral to
    alkaline condition.
C': zone of cation exchange under alkaline condition.

"lateritization" by the writer's usage refers to the whole mineral assemblage
in the zonal arrangement.

b. Incomplete laterite profile in soils on slopes of mountains, hills and plateaus

Slopes of mountains, hills, and plateaus are usually covered with thick
tropical forests. In an area of granite, gneiss and other crystalline basement
rocks, kaolinitic, sticky soil is the usual product of weathering.

In Oiapoque, an unusually sticky, red and reddish yellow mottled, homo-
geneous kaolinite, apparently free from quartz grains was found on the high
slope close to the edge of a plateau, about 60 m above the sea level. Near
the foot of the same slope lay an irregular bed of transported bauxite, up to
5 m thick. It was suspected by the writer that the sticky kaolinite was a
remnant of an old laterite profile, which used to have some amount of bauxite
crust on top.

Near Paredão Falls, Rio Araguari, Amapá, a profile more than 2 m thick
of orange yellow to orange red, kaolinitic soil is well exposed along new road
cuts for the highway, 14 km long, which leads from the top of Serra da
Pancada down to the Paredão Falls. The area is covered with thick forest.
The basement rock is hornblende gneiss. Limonite concretions are very rare.

Near Camaipé, Rio Vila Nova, Amapá, a test pit near the edge of a pla-
teau, about 30 m high above the river, show a kaolinitic profile, more than
2.2 m thick. It contains much quartz grains. The color varies from yellow
to reddish orange in the depth.

These kaolinitic profiles on all of these forested and steeper slopes are
characterized by a very thin top sandy layer A_1, which is less than 25 cm
thick and dark gray with humic substance. The kaolinite is more fluffy and
sandy near the surface but gradually gets more compact and sticky in the

depth. Color varies from yellow or orange near the surface into reddish orange or red and white mottled at depth. All these changes are gradational and no sharp lines of demarcation occur to separate out zones (Fig. 9a).

The direct contact with the basement rock has not been observed in the above cases.

These kaolinitic profiles are called incomplete or immature because they lack in concretions or crusts of limonite as well as of bauxite on top.

c. Intermediate laterite profiles in soils on forest covered plateaus and low-
   lands

A kaolinitic profile with a thicker top sandy layer (150 cm±) but without any limonite concretions is seen on a forested but gentler slope near the foot of a mountain. This is exposed on a railroad cut at a point between the Serra do Navio mine and Pedra Branca, Rio Araguari, Amapá (Fig. 9b).

The top sandy layer (A) is the same as in the profile a and is dark gray bleached sand with a small amount of clay. Then follows, without any sharp boundary, a yellow, fairly sandy horizon B_1. Although it shows leaching of kaolinite, it does not show leaching of iron hydroxide, whose presence is shown by the homogeneous, yellow color. It contains no limonite in concre-tions but contains occasional fragments of angular vein quartz. This seems to indicate that this layer consists in materials which are gradually moving down the slope. The kaolinite is mottled or striped with red limonite stains.

The boundary between the horizons B'_1 and B'_2+C' is clear.

Another type of profile seen on the forested flatland along the Araguari river is shown in Fig. 9c. The usual (A) with some humus is followed by light grayish yellow fine sand A′ with a small amount of clay (perhaps less than 30%). A′ is followed, with fairly sharp boundary, by B'_1 with iron con-cretions. These iron concretions are small in size (dia: 1–5 cm) and are only sparasely distributed in the upper part of B'_1. In the lower part of B'_1 oc-casional fragments of vein quartz are seen.

The boundary between B'_1 and B'_2+C', which is mottled kaolinite, is sharp.

In the writer's opinion, an intermediate laterite profile is characterized with the growth of a zone (B'_1) of intermediate sand/clay ratios of about 60/
40 (see Fig. 9b).

Under a climate of tropical rain forest type, the litter grows thick and the top soil is disturbed by the surface run-off to a less degree. And the rate of growth of B_1 is almost negligible.

While, under a climate inclined to a tropical savannah type with a con-centrated precipitation, the surface run-off gets strong enough temporarily so that it disturbs the top soil and disperses and carries away clayey particles. The intermittent filling and draining of the pore spaces will accelerate the pro-cess of "elutriation" of finer particles. The coarser particles of sand size may be moved for shorter distances, but get trapped on flat surface of plateaus and lowlands.

Thus the change of climate from tropical rain forest into tropical savannah type, and flat surface of land seem to account for a more rapid introduction of

a zone B'_1 of an intermediate sand/clay ratio.

Where the surface of plateaus, etc., even though flat, is underlain by quartz free rocks such as old bauxite and iron crusts, diabase or quartz free sedimentary rocks, there would naturally be no sandy top soil unless quartz sands are carried into it from outside.

The writer has recently made the following observations along the new highways under construction near Manaus: Manaus-Rio Branco and Manaus-Itacoatiara highways. Between the points 25–38 km, the Manaus–Itacoatiara highway passes over the nearly flat surface of a plateau, about 50 m high above the level of local "igarapés". The soil is yellow silty kaolin to the top. Only grains of hardened silty kaolin with occasional quartz sands (both 1–2 mm in dia.) are strewn over the surface.

In other areas, these highways traverse a terrain of undulating hills with slightly lower altitudes, and we can see laterite profiles well exposed along numerous road cuts. These are typical intermediate profiles with a string of small limonite concretions at varying depths of 2–7 m in B'_1.

d. Complete laterite profiles in soils on grass covered plateaus and lowlands (campos)

Profiles of this type are well exposed on the numerous cuttings along the new ICOMI railroad which runs over a campo for a distance of a little over 100 km from Porto de Santana to Porto Platon, Territory of Amapá.

Near Porto de Santana, a cutting, about 4 m high and over 300 m long, shows a continuous section of a complete laterite profile, which is shown in Fig. 9d.

The top sandy layer consists of (A) and A' layers. (A) is gray and A' is yellowish gray in color. Their clay content seems to be less than 30%.

B'_1 is the zone of iron concretions which are larger in size upward. Large concretions range in diameter from 5–20 cm or considerably more. The boundary between A' and B'_1 is very sharp and wavy.

$B'_2 + C'$ is mottled kaolinite (reddish yellow silty kaolinite with brown stripes of limonite, and purple and white specks of kaolinite). The boundary between B'_1 and $B'_2 + C'$ is very sharp.

The zone B'_1 with concretions is exposed on the land surface on top of slight "highs" and along the "edges" of the campo. Since the railroad cuts through these "highs" and "edges", almost stereotyped profiles of complete laterite are exposed on nearly all of the large and small cuts.

On perfectly flat land or slightly depressed land between these "highs", however, the surface is covered with a thicker sandy layer which apparently receives its material from the top layer of the laterite of the "highs" on the surrounding ground.

Underneath these thicker sandy layers, the zone of concretion appears to diminish in its thickness or even entirely disappears. So the profile approaches to that of an intermediate type.

Along the highway from Ferreira Gomes to the town of Amapá, a thick limonite crust, sometimes bauxite, is found along the edge of plateaus with an

altitude of about 100 m or more above the sea. The crust is 2–3 m thick and encircles the edges of plateaus or mesas.

In Oiapoque, a crust of ferruginous bauxite, about 7 m thick, covers a diabase on top of a hill.

The formation of these thick crusts probably dates back to Tertiary times. Other laterite profiles on the campo of Pancada (along the ICOMI railroad) or along the Rio Araguarí are probably of Pleistocene age.

Along the Rio Baixo (lower) Tapajós, occasional huge boulders of limonite crust, a few to several meters in diameter, are toppled down and lie on the beach beneath the Tertiary plateau. Although the profile in situ has not been studied, the thickness of the crust and the supposed place of origin–i. e. the top of the Tertiary plateau–suggest its Tertiary rather than Pleistocene origin.

e. Silicification of top layer—the so-called tropical podsolization

Silicification of top layer

All of the above stated laterite profiles are capped with very sandy layers of variable thickness. Their clay content amounts up to about 30%.

The uppermost part of the sandy layer is a part of modern soil and is denoted with (A) in the following diagram. Other parts of modern soil (B) and (C) are not shown here, but will be discussed in a following chapter.

These sandy layers are underlain by different materials in different profiles. The following diagram shows the usual thickness of capping sandy layers (A) and A′, and of underlying material of profiles at different stages of lateritization.

The kaolinite in $B'_2 + C'$ horizon is already a product of leaching by freely circulating water. But when it is in contact with freely circulating acid water near the surface, it is gradually dispersed and transported away from the system. Quartz is not affected by the acid water. So, quartz sands of unsorted, coarse and fine grain size, remain behind to form the " capping sandy layer ".

The dispersion of kaolinite is most vigorous under forest where the surface water is acid, and perhaps more so where the surface runoff disturbs the top soil mechanically. On sloped forest land, however, sands slide down along the slope. Thus the sandy layer is thin up on the slope and tends to become thicker on the gently sloped forest at the foot. Occasional fragments of vein quartz show that the intermediate sandy layer together with the sandy layer above is gradually shifted downward.

On the forest land the dispersion of kaolinite is strong and the sandy layer grows slowly on flatlands on top of plateaus and faster at the foot of a slope. However, the limonite concretions are either non-existent or very small in size and density in the intermediate sandy layer. This is due to the fact that even the top sandy layer is moist throughout the year and the water is perennially acidic.

On the grassland, however, the formation of limonite concretions is most manifest. This seems to be due to the higher pH of the underground water and to the fluctuation of the ground water table. In some cases solution relics

Fig. 9   Diagram showing the development of sandy top layer of laterite profiles (Thickness in cm.)

Physiography	Sloped forest land	Gently sloped or flat forest land	Flat grassland
Stages	"Incomplete"	"Intermediate"	"Complete"

Lithological succession

a: (A) 25 B'_2 300—   1000+   C'

b: 25 B'_1 120 B'_2 550+   C'

c: 20   50–120   30 —   .100   150+

d: 0–25 (A)   0–45 A'   40 B'_1 260+ B'_2 C'
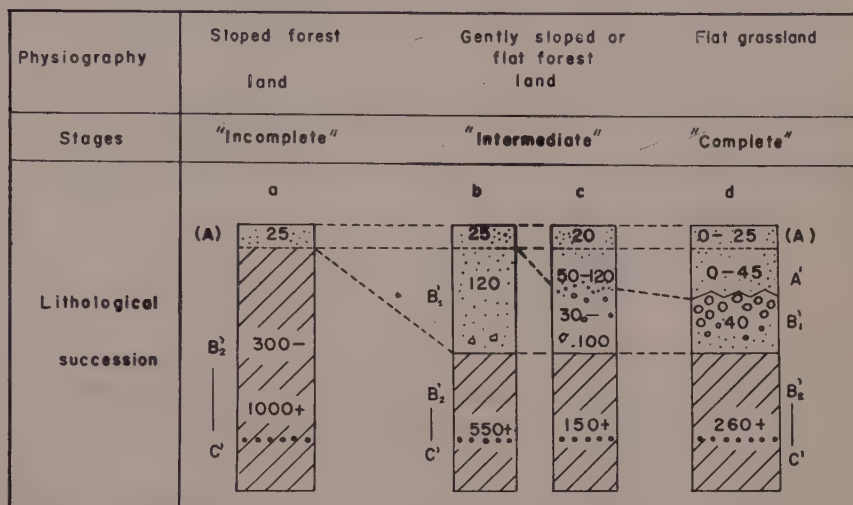
a: Pontanari, Oiapoque, Territory of Ampá ; Foundation of the crushing Plant, Serra do Navio Mine.

b: Railroad cut between Serra do Navio and Pedra Branca,

c: „   20 km south of Pedra Branca,

d: „   near Port Santana,   „

(A):   Modern soil profile – (B), (C) not shown on the profile.

A′,B′₁, B′₂+C′:   Laterite profile.

(A):   Sandy layer with sand/clay ratio=70/30± Dark gray with humus

A′:   Sandy layer with sand/clay ratio=70/30± Light gray without humus

B′₁: Intermediate sandy layer with sand/clay ratio=60/40±

B′₂+C′:   Clayey (Kaolinite) layer with sand/clay ratio=40/60±

———— Sharp boundary

------- Fairly sharp boundary

• • • • Transitional   „

○ ○ ○ ○ Large limonitic concretions: dia=5-20cm or more

ė ○ ○ ○ Small   „   „   : „ =1-5cm   „

○ ⊘ c   Occasional fragments of vein quartz

of limonite concretions are sparsely distributed in the top sandy layer above the sharp boundary on top of limonite concretions. The dispersion of kaolinite is also observed on the sometimes rugged, saw-toothed boundary between B′₁ and B′₂+C′ (especially on the head of gullies).

Generally speaking, the boundaries between (A), A′, B′₁ and B′₂+C′ are all gradually descending, leaving behind a sandy top layer consisting predominantly of quartz sand ((A)+A′). This is the silicification of the top layer of all the laterite profiles. The development of a quartz sand layer and the process of its formation are analogous to the formation of a porous chalcedonic quartz cap on top of an alunite deposit.

Tropical podsolization

Lateritization is the process of general desilication. Therefore this silicification is a retrogression of the process of lateritization and may be called a tropical podsolization.

These quartz sands are often washed down into perennially wet depressions and bleached snow white by the water with low pH and Eh. Some authors apparently refer only this "snow white bleaching" of sands to tropical podsolization.

Lateritization, a process of residual enrichment of stable elements on the earth's surface

The horizon $B'_2 + C'$ of laterite on diabase does not contain quartz. But the same horizon of laterite on gneiss, granite, etc. and also on sedimentary formations interbedded with sandstone, is heavily laden with quartz grains which are the remmants of the primary constituent in parent rocks.

While the silicification is going on upon the surface, the decomposition of basement rock is also going on underneath the profile. The presence of three-layered minerals such as montmorillonite is sometimes suspected by the writer (as in the profile on supposed mica schist near Serra do Navio) but not yet verified by mineralogical tests.

It seems that in the tropics the circulation of the underground water is too vigorous even at the very contact of the lateritic profile with the fresh basement rock in the depth. This is not only on account of its amount but also on account of its reduced viscosity due to higher temperature. So, montmorillonite, if formed, is supposed to be extremely short lived because of its too high activity and gets transformed into kaolinite. In the writers opinion this is true because it takes a high concentration of cations and limited amount of OH or water to produce and keep three layered clay minerals within the system.

On a flat basin on the earth's surface under tropical conditions, a chemical decomposition rather than mechanical disintegration is naturally a predominant factor in rock weathering.

From the sedimentological standponint, it is a geochemical "beneficiation table" on which elements of rock-forming minerals are classified and a large amount of concentrates of so-called hydrolysate elements are obtained. It may be compared even with the strong magnetic field in a mass spectrometer where an ion beam is resorbed into a number of separate beams with different paths according to elements or isotopes.

Such elements as Na, K, Ca, Mg, etc. (ionic potential or charge/radius <3) go into solution as cations. Such elements as C, N, P and S, etc. (ionic potential >12) form acid anions and also go into solution.

Only those elements: Al, Fe, Mn, Si, etc. (ionic potential from 3 to 12) form precipitates of insoluble hydroxides and can remain on the surface of the

basin. K has a strong tendency for being adsorbed by three-layered minerals to form illite.

These cations released in the underground water, and acid anions formed in the surface water by oxidation, on their way of departure from the parent rocks, are responsible for an orderly zonal arrangement of precipitates of hydro-lysate minerals in the weathering crust. This is because the hydrolysates or clay minerals, including SiO_2, are in equilibrium with the media with which they are in contact (30).

The nature and reaction of media are controlled by the ground water table. So, it is natural that a regular sequence is found in laterites in different countries and furthermore, that it is similar to the sequence found with alunite deposits.

f. Climate and shifting of forest—grassland boundary

Evidences of destruction of an old limonitic crust on top of hills by forest have been observed by the writer on hills near the airport, Oiapoque, and also on a hill near Coroatá—Pedreira highway junction, in Maranhão.

Evidences of retreat of forest, however, are not so clear as those of the destruction of limonite crusts by it.

In the suburb of Manáus along the Itacoatiara highway, a few isolated patches of "forest clearances" are marked on the map (C. N. G., 1/1,000,000).

It is suspected by the writer that some of these are natural grasslands, because there are some road cuts near-about in which complete laterite profiles with limonite concretions are observed. In the neighboring forested flat lands, nearly horizontal strings of tiny limonite concretions are observed at the depth of several meters from the surface in sandy clay soil. This may be considered as an intermediate profile, but not a destructed old profile.

To the south of Porto Platon, at a point about 80 km on the railroad from Porto Santana, there is a cutting about 3 m high near the edge of a plateau. The profile on this cutting is unique because it shows the usual thick gray and grayish yellow top sandy layer (A)+A′ about 100 cm, but this gradually merges into reddish yellow and orange red, clayey horizon in the depth. So, this profile, in spite of its present position on the campo, shows a similarity to the forested slope profile, only with a thicker top sandy layer.

The forest of Matapí is only a few kilometers to the west of this point. So, it is possible that this point used to be occupied by a part of the large forest or by one of the islands of the forest which has recently retreated west-ward.

The natural high grasslands (campos altos) in the north Amazon are dis-tributed in Rio Branco, on the slopes of the Guiana plateau (interfluves of up-streams of the Rios Trombetas, Erepecurú, Cuminá, Maicurú and Parú).

It is noteworthy that the concentration of annual precipitation in wet and dry seasons is most manifest in these regions.

The high concentration ranging from 1/7 to 1/10 for a dry half year in Amapá and Rio Branco and the wide distribution of campos altos in the same region attract our attention. It appears to be possible that such intermittent

Table 5. Table showing the concentration of the annual precipitation in the Amazon*

Locality	Year	Monthly precipitation (mm) I II III IV V VI VII VIII IX X XI XII			Annual	Concentration: Dry semi-annual / Total
Soure, Marajó	1946/1955	2379.42		870.58	3250.00	1/4 +
Belém	1954	1648.50		633.30	2381.80	1/4 +
Santarém	1946/1955	1833.37		478.63	2312.00	1/5
Manáus	1954	1629.60	326.50		1956.10	1/6
Macapá, Amapá	1954		1720.70	265.30	1986.00	1/7
Boa Vista, Rio Branco		187.4	1700.10		1887.00	1/10

* Calculated from original table of monthly precipitation, compiled by Dr. J. Biard. FAO Mission in Amazon, S. P. V. E. A. Belem.

dry and wet seasons are responsible for the formation of campos and therefore a complete laterite profile in soil.

Roseveare (1948) cites Luetzelburg and Bouillenne and makes a following statement in her work:

"The most important Amazonian savannahs are situated in the northeast on the Rio Branco towards the frontier of the Guianas, and in the lower Amazon reach between the great Rio Negro and Rio Xingú tributaries, which is a zone of lower rainfall and strong winds in the dry season. In the eastern part of the latter region, namely, that in the State of Pará, the dry season is much more accentuated than in the western part in the State of Amazonas, and it is perhaps to this that the presence of numerous savannahs in the Pará (including Amapá) region is "due", etc. (25).

Fritz Kerner-Marilaun of Austria once calculated what he called a "laterite number (L)" from precipitation and temperature of regions, in which laterite is found, all over the world (15).

$$L = R^{-1/4} \cdot (S-s) \cdot t_m \cdot 100^{-1}$$

     where

     L : Laterite number

     R : Annual precipitation (mm)

     S : Wet semi-annual precipitation (mm)

     s : Dry   „   „   „   (mm)

     t_m : Minimum monthly mean temperature (°C)

     $R^{-1/4}$: is obtained by $R^{3/4}/R$, where $R^{3/4}$ is thought by Kerner-Marilaun to be proportional to the amount of infiltration (mm).

Kerner-Marilaun proposed that any region with $L > 50$ is under an optimum condition for the formation of a laterite profile. This is his statistical deduction from the meteorological data of regions where complete laterite profiles are actually formed over the world. A moderate amount but high concentration of annual precipitation and high temperature seem to be necessary conditions.

Both Amapá and Rio Branco show L values slightly over 50. If similar climatic conditions existed during the Pleistocene, we must admit that it is quite natural that we find extensive laterite in these regions.

A high amount of annual rainfall, evenly distributed throughout the year, will substantially reduce the L value. These are necessary conditions for tropical rain forests. Under these conditions, infiltration increases and the soil profile is perennially wet with water of low pH and low Eh.

Under these conditions iron hydroxide is not stable and only kaolinite is stable. Thus, the profile remains incomplete and does not mature into a complete profile with limonite concretions and bauxite. If pH is sufficently low, kaolinite will become gradually dispersed and move out of the top layer leaving only a sandy material mixed with humus.

g.   Physiographic control of ground water drainage- Origin of grassland

Grasslands are usually found on sandy soil. Extremely sandy soil can be usually found on flatlands rather than on sloping lands. These sands may be a thin veneer of residual top soil which has grown extremely sandy or a layer with variable thickness of sediments washed down the slopes into lowlands.

Wherever the sands get too dry during dry seasons, there seem to develop grasslands.

The origin of the thin veneer (20-150 cm±) of sandy top soil on flatlands attracts our attention. In the writer's opinion, this seems to be closely related to the process of lateritization.

Suppose we have a forest covered plateau fringed with forest covered sloping land. The faltland on top would probably be covered with kaolinitic soil of intermediate laterite profile whereas the sloping land would have a kaolinitic soil with an incomplete laterite profile.

Suppose the basement rock is either granite and gneiss of the crystalline massif or Tertiary sediments with quartz, usually kaolinitic sandstone. Then we would expect the kaolinitic soil to contain normally up to 40% of quartz grains of sand and silt size. This percentage gradually rises as the surface is approached, until finally a "top sandy layer (A)" is reached. (A) is very sandy and dark gray with a varying humus content.

So long as the annual precipitation is fairly high and its concentration is not too great, the forest land remains wet throughout the year. But as the annual precipitation decreases, the drought is first felt by the flatland on top of the plateau. This is known from our observations of the extensive plateaus on the divide of Mato Grosso, Goiás, etc., which are covered with grassland (cerrados) under comparatively arid condition. Flatland on top of plateaus and mesas are all grassland, while slopes facing gullies and streams are sometimes sparsely and at other times very thickly wooded even with rubber trees and form "forest ribbons" following the river courses (in Mato Grosso).

This is also observed in the thick forest on the slopes along the Araguarí river that fringes the campo on the Serra da Pancada, Territory of Amapá.

During the rainy seasons the surface soils both on the flat upland and on the slopes are saturated with water. The kaolinite particles are dispersed in

water and carried away as it drains off, and sands are left behind.

On flatlands on top these sands are trapped and remain in place and form gradually a thicker bed of nearly clay free sands. While on the slopes these slowly creep down (Fig. 9b and c profiles showing fragments of vein quartz) due perhaps to their own increased weight and decreased rigidity when saturated with water. As the surface sands are slowly removed by downhill creep, deeper layers with more clay are brought closer to the surface to have their clay content subjected to more active dispersion.

After a sufficiently long period of time, the top sandy layer on the flat land grows much thicker than that on the sloping land. Thus we find an intermediate laterite profile on the flatland and an incomplete laterite profile on the sloping land.

The attraction of soil for water is shown by " capillary potential " with a negative sign. Clay may contain six to seven times as much water as sand at the same potential, i. e., sand can be drained much more easily than clay.

After the sandy layer on a plateau gets saturated during the rainy season, it releases the water gradually by gravity. The water thus released travels, in a phreatic movement according to the gradient, toward the edge of the plateau and further down the slope into the valley.

The role of the soil on the slope is to transmit the underground water downward. Because the soil has the high negative potential even at high moisture content, it can distribute the moisture even close to the surface and keep it there against the gravity.

Thus the soil covering the surface on the slope gets the water that fell on the plateau long after the rainy season is past and the ground water table has sunk downward. In other words, the capillary fringe is large enough to cover the whole profile on the slope.

The most striking difference in physical conditions of the flatland on plateaus and in those of sloping land is the effect of fluctuation of ground water table.

When annual precipitation decreases to such an extent that the ground water table is lowered too deep for plant roots, or an impervious bed rock is too shallow for them so that enough moisture can no longer be supplied to the plants, those plants have to retreat from the top of the plateau.

Thus, the factors that determine the beginning of the retreat of a forest are the capillary potential of soil, the amount of lowering of ground water table and the depth of the impervious bed rock. In other words, a very sandy top layer of soil underlain abruptly by very compact clay with small amount of available moisture and dry climate seem to be sufficient conditions.

The fluctuation of the ground water table under intermittently dry and wet seasons accelerates the dispersion and leaching of kaolinite and gradually make the soil on the flatland more and more sandy. Under such condition, a spell of drought can kill the forest and make a grassland on the plateau but not on the sloping land.

After the forest has retreated, grasslands take over the top of the plateau

and the precipitation of iron hydroxide near the surface become possible due to the general rise of Eh and pH. Iron moves in solution downward through the sandy layer and gets precipitated where the pH rises. More iron moves laterally along the clayey layer and gets precipitated when the solution meets with descending water with a high Eh. Thus, the iron concretions are formed where sands and clay meet or approximately on the water table.

As the water table fluctuates, its amplitude is the largest on the cliff edge of a plateau. Because the precipitation of $Fe(OH)_3$ and also $Al(OH)_3$ takes place approximately at the water table, those points with the largest amplitude of fluctuation get the thicknest deposit of these minerals. This is why iron and bauxite ore deposits of economic importance usually occur on the cliff edge of a plateau and in horizontal ledges on its slope.

It is not likely, however, that any bauxite ore deposit of economic importance will be found among lateritic concretion zones in a thin profile of the total thickness of only several meters. The phosphatic bauxite on the Trauíra Island, Maranhão is a part of a laterite profile which is over 34 m thick. The formation of this kind of thick laterite profile, probably dates back to Tertiary and even to Cretaceous-Eocene ages.

When the climate changes again to a perennially wet one with a sufficiently large precipitation, the forest soon thickly covers the plateau and not only keep the laterite from maturing but also can destroy a once complete laterite profile. Such examples have been observed by the writer on the hills near the airport, Oiapoque and near Coroatá-Pedreira junction, Maranhão.

Around the outcrops of the great manganese ore bodies, at Serra do Navio, Amapá, there are large quantity of round grains of MnO_2 in the surface soil. They are nearly spherical grains of the size of shots for a gun to beans. This possibly shows the solution and redeposition of MnO_2 due to the change of Eh and pH. This can also be taken as an example of the destruction of laterite on a small scale.

The forest—grassland boundary may in some cases be in such a delicate balance that it can be broken by human influences—for instance clearing by fire, etc. (26). The clearing may introduce a locally drier climate and accelerate the retreat of forest.

The formation of limonite concretions is, in general, the result and not the cause of the retreat of a forest.

C. Superimposition of recent soil profile on fossil soil— or laterite profile in the Amazon

As it has been shown on Fig. 9 in section 4-B-e, a thin but very sandy layer (A) caps and truncates the top of all types of lateritic profiles. It contains varying amounts of humus and is dark grey under a forest and light grey on a grassland.

This sandy layer is evidently the product of modern soil formation. This top sandy layer is followed downward by other layers or horizons of modern soil. During the excursions of the meeting of soil scientists held in Belém in

1956*, the wirter had the opportunity to study, together with these soil scientists, different soil profiles in Amapá and Maranhão.

The soil profiles in test pits sunk by them are usually classified into A_1 A_2 A_3, B_1 B_2 B_3, C_1, etc. A_1 is the top sandy layer with humus, then follows A_2 and A_3 which are usually grey, sandy or friable horizons. The total thickness of A_{1-3} varies from 20-70 cm.

Then follow B_1 B_2 or B_3 which are yellow or brown, iron stained, and sometimes contain Mn concretions. The total thickness is from 50-150 cm.

The test pits were sunk on grasslands, forests, cleared forests, mountain slopes and hill tops, etc., so they struck different types of laterite profiles at different places.

In some cases A and B were in the horizon C′ (with 50% or more of undecomposed Devonian red shale). In other cases A and B all fell within A′ sandy layer. When B fell on B'_1, it was over 150 cm thick at the pit bottom and possibly extended further down.

In the writer's opinion, forest soils as well as grassland soils have deep profiles of kaolinitic soil, these are all lateritic soil. Their formation dates back to the Pleistocene or even to earlier ages, the different horizons of the profile are the net results obtained under different physical and chemical environments which prevailed through very long period of time.

The present environment indicated by the "laterite number" appears to coincide with the actual distribution of laterite on grasslands. But the present climatological environment in the Amazon in general may very probably be different from that under which the different lateritic profiles were built over the Amazon in the past.

Thus, the laterite profiles are fossil soil profiles and a modern soil profile is superimposed on them.

In view of this dual character of soil in the Amazon, it would be convenient to use a double symbols system for the notation of soil horizons.

Examples of double symbols:—

A′ A
A′ B

B_1' C	B'_1 A
B_2' —	B'_2 B
C —	C′ C	C′ A
		C′ B etc.
		C′ C

A′A, A′B or B'_1A, etc. are those soils on "terras firmes", etc. in the Amazon which are said to be too much leached of their bases and low in fertility.

This system appears to help an easier understanding of the soil associations on the "terras firmes", plateaus, etc. (31).

D. Lateritization versus podsolization—Origin of bauxite and manganese

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* II Reunião-Definição dos Problemas de Sólos. Meeting at Instituto Agronômico do Norte, Belém: Excursion.

Fig. 10   DIAGRAM SHOWING STAGES OF LATERITIZATION AND PODSOLIZATION
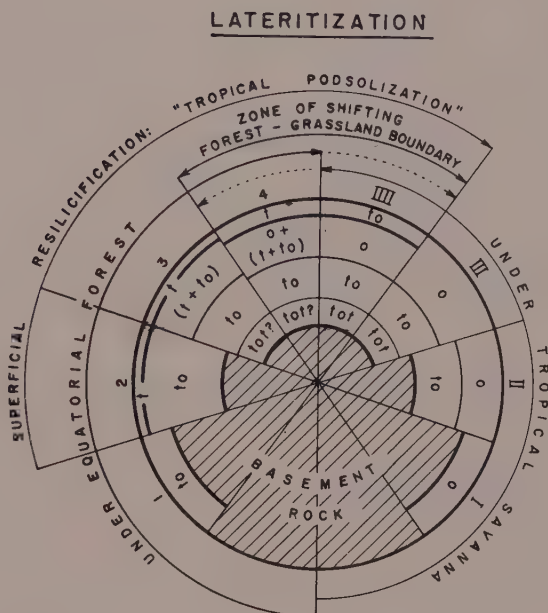
deposits in the Amazon
a. Lateritization under Savanna

The optimum condition for the process of lateritization to occur is gene-
rally supposed to be found under a savanna condition. The " laterite number "
(see 4-B-f) by Fritz Kerner-Marilaun is an attempt to evaluate its effects
numerically.

In the writer's opinion, the normal process of lateritization can be followed
in four stages (I-IIII in Fig. 10).

Stage   I : Bauxite (o) or iron ore (o) is formed on the surface. This is the
            stage in which the front of o-minerals (boundary between accumula-
            ting mass of o-mineral and the basement rock) overtakes fronts of
            other type minerals. This is more frequently known on such alkali
            rocks as phonolite or nepheline syenite.

Stage   II : Kaolinite (to) accumulates beneath bauxite, etc. (o).   The front of
            to-mineral proceeds faster than that of o-mineral, and overtakes
            that of tot-minerals.

Stage III : Montmorillonite, etc. (tot) accumulates beneath kaolinte (to).   The
            progress of fronts of o-and to- minerals is so slackened that tot
            minerals accumulate into mass as their front proceeds downward
            faster than the above two.

Stage IIII : Occasional invasion into a savanna by forests turn the top layer of
            bauxite into kaolinite.   So-called " siliceous bauxite " on top of
            Arkansas deposit and kaolinite on top of and also in funnels pene-
            trating the Georgia deposit, U.S.A. have been observed by the writer.

b. Lateritization under equatorial forest

Under an equatorial or tropical rain forest, the weathered product is re-
presented by a very thick profile of Kaolinite (to). Its thickness (3-10 m or
more in the Pleistocene profile) is only equalled by the thick kaolinite in the
normal laterite profile under savanna.

The writer understands that the thick kaolinite under an equatorial forest
represents an incomplete or immature laterite profile because it lacks in the
bauxite or iron ore (o-mineral) cap. But given a chance it matures into a com-
plete laterite profile.

The formation of kaolinite implies desilication of its parent minerals and
it is a step toward the formation of bauxite (o), that is, lateritization proper.

The lateritization under equatorial forest is also followed in four stages
(1-4 in Fig. 10).

Stage 1 : Found on the surface of diabase. Also, expected to be on the surface
            of alkali rocks, etc., which are free from quartz.

Stage 2 : Incomplete laterite profile (4-B-a).

Stage 3 : Intermediate   „   „   (4-B-b).

Stage 4 : Complete laterite profile brought forth by the retreat of forests, in-
            troducing the grassland (savanna) envionment.

Thus the stages IIII in the previous chapter and 4 as described here, in-
dicate a zone of shifting forest-grassland boundary.

c. Podsolization proper

A Podsol proper is a rather sandy soil found extensively under the forests of the frigid zone under higher latitudes over the world, and is characterized by a greyish white, bleached horizon.

It shows an acid reaction under the forest. In one case in Hokkaido, Japan, the forest was cleared and then volcanic ashes fell in the area. The podsol showed no more an acid reaction.

The chief constituent mineral of colloid size in podsol is thought to be H-montmorillonite or a so-called acid earth or fullers' earth.

The basement rock gets decomposed into the first product of weathering, which is in the writer's opinion three-layered clay mineral (tot): alkali—or alkaline earth montmorillonites. No sooner are these montmorillonites formed near the surface, than they get trapped in perennially acid conditions under the frigid zone forests. They get their cations exchanged with H^+ and become H-montmorillonite, which is the only clay mineral that is stable under a strongly acid condition.

The profile of podsol proper is usually very thin=about 1 m±. (Fig. 11).

d. Origin of bauxite deposits in the Amazon—Lateritization under savanna

Fig. 11. Columnar section showing the profile of the phosphatic bauxite deposit on the Trauíra Island, Maranhão

Thickness on north coast	Pro-file	Lithology	Chemical analysis (%)			
			SiO_2	Al_2O_3	Fe_2O_3	P_2O_5
2 m		Ferruginous, Pisolitic ore	12.0	25.3	19.8	16.4
8		Ferruginous, Pseudo-brecciated ore	0.6	9.0	41.5	24.5
6		Non-ferruginous, Stalactitic ore	16.1	25.0	3.7	28.8
7		Non-ferruginous, Porous ore	2.5	41.2	4.1	25.9
11		Mottled kaolinite	—	—	—	—
		Hornblende gneiss ?				

Above section shows the profile of a common bauxite later phosphatized. The thickness of the total profile amounts to 34 m as exposed above sea level. We can expect some more kaolinite and perhaps montmorillonite below. So the total thickness may reach 40 m or over. A laterite profile of this thickness is one of the thickest of the world (the lateritic bauxite profile on the Bintan Island, Indonesia is 54 m thick according to Dr. Van Bemmelen, and is the thickest so far as the writer knows).

The formation of this great profile of bauxite probably dates back to the Tertiary and even to the Cretaceous-Eocene age. Similar but less phosphatized deposits are known on hills a short distance inland on the neighboring coastal plain of Maranhão.

Bauxite ores of good quality are found in the lateritic crust on the edge

of the plateau, about 100 m above sea level, near the town of Amapá. Rede-posited bauxite is also known on the slopes some distance below the edge of plateaus, 60 to 120 m above sea level, near the town of Oïapoque, Territory of Amapá.

A very ferruginous bauxite deposit about 7 m thick is known from the hills near the airport of Oiapoque. These hills are about 30 m above the river level.

The formation of these deposits in the Territory of Amapá probably dates from the Tertiary age.

The abundant lateritic iron concretions found on the grassland in Amapá, have not been known, so far, to be accompanied with any bauxite ores. These iron concretions are, as has been stated in the chapters 2-B-a et seq., the pro-duct of stage 4 of the " lateritization under equatorial forest ". Being in the zone o+(t+to) (Fig. 10), the limonite(o) is mixed with too much of quartz(t) and kaolinite (to).

The good bauxite, possibly of the Tertiary origin in Amapá, may be the product of the " lateritization under savanna ". The bauxite in this case is formed, to a greater extent, in a crust directly in contact with the decompos-ing mother rock, that is, in an environment where plently of alkaline solutions are available to get rid the system of quartz (Stage I). On the other hand, the formation of those limonite(o) concretions or bauxite(o) if any on the grassland, starts on top of thick kaolinite(to) where only a small amount of alkaline solution is available and quartz grains cannot be eradicated so soon.

In any case, there is a better chance of finding bauxite of good quality with older lateritic crusts. These older lateritic crusts are expected to be frin-ging plateaus of Tertiary or even Cretaceous ages, which are normally 100 m to 400 m or more in their altitudes above present sea level. However, near the Marajó graben and along the maritime regions, the upheaval seems to have not been large, and consequently, the plateaus of these ages can be expected to be much lower (for instance, the Trauira Island). There are also chances of finding reworked or redeposited bauxite deposite in later sediments which occupy the lowlands in the neighborhood of these old crusts on plateaus.

In French Guiana, " cuirasses latéritiques et bauxitiques " appear to cover flat tops of hills 200 to 370 m above sea level, and also lower ledges on their flank and top of lower hills even less than 100 m or less above the sea. These " cuirasses " seem to be traced more or less continuously on tops of hills or mesas of the same altitude and also along the ledges of the same level (10). These are formed on the pre-Cambrian schists and basic volcanic rocks, and are usually ferruginous.

According to M. Choubert, lateritic crusts on plateaus are older than Qua-ternary, but those on marine terraces, also on pre-Cambrian rocks, are built during " glacial or regressive stages under tropical (savanna) climate ". As for the altitudes of the marine terraces, he mentions that " there are marine ter-races with similar elevations with those formed in the Quaternary age in Africa and southern Europe ". He probably means these altitudes to be less

than 80 m.

According to M. Choubert, there are also small lateritic clay deposits among Quaternary sediments on very low marine terrace (25 m) (10).

In Dutch Guiana, two types of bauxite deposits are known: the highland —and the lowland bauxites. The highland bauxite is found as a ferruginous bauxite of lateritic crust capping epi-diorite on a plateau as high as 500-600 m above sea level. A part of the lowland bauxite is found interbedded with basal Quaternary sands and clay. In the opinion of J. P. Bakker, these appear to be Quaternary sediments bauxitized in place. In other part of the lowland, bauxite is known to cap pre-Cambrian schist and is evidently the weathering crust of the latter in situ. The level of the lowland bauxite is usually 35-40 m or less above sea level (4).

In British Guiana, bauxits deposite appear to cover hills up to about 200 m high above sea level. The hills are composed of gneiss and granite. The bauxite occurs in a zone of these hills situated close to the lowland of basal Quaternary beds. The ore bodies are in a large turtle-back shape following the configuration of those hills, and "range in thickness from a few feet up to 40 feet" (5).

According to Bracewell, the bauxites "occur as cappings on an old land surface, now generally buried beneath the sediments of the White Sand series, and are exposed only where recent erosion has removed these sediments. The belt within which the deposits lie appears to be related to the line joining the points of emergence of the crystalline basement from beneath the coastal sedimentary series" (6). He also mentions that "they (White sand Series) are more or less continuous with the coastal sedimentary series" (7).

The coastal sedimentary series is 1900 m thick near the month of the Berbice river and is thought to be of Miocene-Pleistocene age.

From what has been stated by Bracewell it seems to be possible that the bauxite is contemporaneous with some part of the coastal sedimentary series, and is over-lapped by younger part of the latter which is represented by the White Sand series. This inference appears not to contradict with what are stated by H. Schols and F. C. d'Audretsch on Surinam (32), and B. Choubert on French Guiana (11).

As has been stated in previous chapters, a strikingly sandy top soil and deposits of sands, apparently washed down from it, often underlie grasslands in the Amazon. These are probably counterparts of the White Sand series in Guianas.

These sands in the Amazon, as has been stated by the writer, are related to the process of lateritization which has cotinued up to this day. It has been pointed out by the writer, at the same time, that bauxite deposits of good quality seems to be found among older (Tertiary and even older) laterite profiles. This situation, inferred by the writer in the Amazon, seems to fit in the general picture of three Guianas.

e. The manganese deposit in Serra do Navio, Territory of Amapá—Lateritization under forest

The manganese deposit is located at Serra do Navio in the middle course of the Rio Araguari, Territory of Amapá. It occupies a zone obout 8 km long across the stream of the river. It is connected by a railroad, 195 km long, with Porto de Santana on the north bank of the Rio Amazon. The railroad runs over the grassland for the first 100 km from Porto de Santana to Porto Platon and from there it runs trough a thick forest along the right bank of the Rio Araguari up to 185 km from Port de Santana, where it crosses the river and reaches the terminal of the mine at Terezinha.

The ore bodies, about 20 in number, are found on or near the top of discontinuous ridges for the distance of about 8 km. The ridges are nearly 300 m, and the Rio Aragauarí at Terezinha is about 90 m above sea level. The ridges are flanked with steep slopes, covered with a very thick forest.

The geological formation in the area is the pre-Cambrian basement and is represented by amphibole schist, mica schists, quartzite, etc., trending in N 45°W, dipping at 45°NE.

The largest ore body measures 450 m in length and about 70 m in depth. All the ore bodies are extremely irregular in shape (Fig. 12).

Although there are abundant large and small boulders along the flank of the ridge, only small parts of large ore bodies are exposed on the surface.

Fig.12 SKETCH CROSS SECTIONS OF MANGANESE OREBODY: T-6, SERRA DO NAVIO
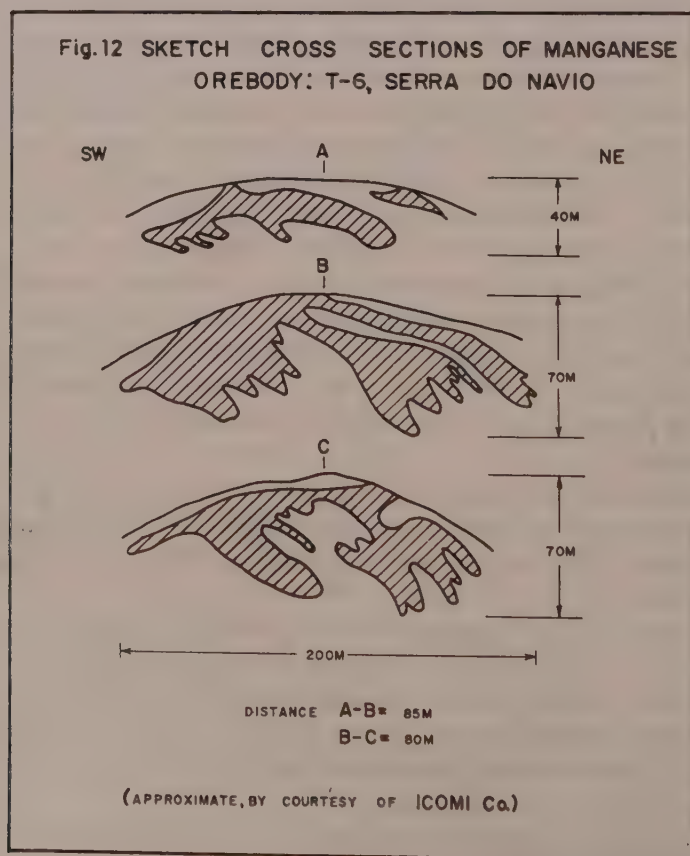
The bottom of the ore bodies is remarkably irregular. Surface indications have no discernible relation to underground depth or extension of ore bodies.

ICOMI Co., therefore, had to make about 200 drill holes to make their estimation of the amount of ore reserves.

The ore mineral is MnO_2. The material with $Mn>46\%$ is considered as ore in the estimate of reserves. The average ores analyse as follows:

Mn	55%
SiO_2	1 — 3%
Al_2O_3	2 — 4%
Fe.	3 — 5%

As to the origin of the ores, a theory of residual enrichment due to weathering is generally accepted. There is no regularity of a sedimentary bed, in the ore body there are no quartz veins with hydrothermal minerals.

The top of the ridge, where cleared of forest, commands a good view of hills and also plateaus in the distance. These ridges are evidently dissected remnants of old plateaus. Judging from their altitudes above sea level, the peneplanation of these plateaus seems to be of the early Tertiary or even of Cretaceous age. The process of lateritic enrichment was possibly initiated already in these early ages.

The Fe and Mn, which are usually closely associated in rock forming minerals, have been separated during the process of lateritization of these ores. This is supposed to be due to the difference of oxidation reduction potential (Eh) for the system containing these elements.

Fe has a lower Eh than Mn, that is, Fe gets more easily oxidized than Mn. The difference in Eh for reactions of these elements is greater under an acid condition, and is much smaller under an alkaline condition (18).

Under the thick forest and thick cover of fallen leaves, etc., the condition is strongly acidic near the surface and gradually becomes neutral to even alkaline in depth. In this acid layer Fe^{++} gets oxidized into Fe^{+++} earlier than Mn^{++} into Mn^{++++}, and Fe^{+++} gets precipitated with only a slight rise of pH in shallow depths. While Mn^{++} is more stable in solution and transported further downward until pH gets much higher and oxidation into Mn^{++++} is effected. Thus Mn penetrates in greater depth more easily while Fe tends to remain closer to the surface.

The iron, remaining close to the surface, is subjected to occasional attacks by strongly acid water in phreatic lateral movement. Therefore, it can not remain permanently under the forest. Mn which has migrated underground deep enough, escapes these attacks by strongly acid, phreatic water and forms residual deposit.

An ore body later brought close to the surface is so strongly attacked by the acid water under forest that the outcrop tends to be very small for the size of the ore body hidden underground.

So, it seems that the lateritization under an equatorial forest is the optimum for a manganese deposit nearly free from iron.

5. Deposition and soil genesis on várzeas

a.   Lack in sediments of glacial tills, aeolian loess and volcanic ashes

The main Amazon and several major tributaries show meanders which are open and not so sinuous as the lower Mississippi in North America. All of the smaller tributaries, on the other hand, show extremely sinuous courses of meanders.

The main Amazon and its larger tributaries are not inactive in eroding their banks, in spite of their very open meanders. We find numerous small scale landslides leaving uprooted trees on the banks. We are also told of occasions where hundreds of meters of banks have been scoured by flood waters and tumbled down in one night.

Those strongly meandering smaller tributaries are even more active in attacking their concave banks. Trees are always seen on the concave banks, uprooted and toppled down into the streams. In fact, the large amount of sediments obtained from the concave banks and the deposit on the convex banks, is the direct cause of the ever increasing sinuosity of meanders.

That sediments are locally being obtained and locally being deposited by the Amazon and its tributaries is shown by the above observations. The bulk of these sediments comes from comparatively recent deposits of Quaternary age distributed along the rivers and subjected to direct attacks by the streams. A much less amount appears to come direct from the Tertiary and older formation, owing to the low elevation and flatness of the land as well as to the luxuriant cover of vegetation.

As has been stated before, the Quaternary sediments are conspicuously small in their magnitude in the Amazon basin, when compared with other large sedimentary basins which occupy the low plains of the world. This is due to the lack in the Amazon, in glacial tills, aeolin loess or volcanic ashes, which characterize Quaternary sediments in other basins of the world.

The bulk of the stream load is being obtained simply in another process of " reworking ", from beds which are already products of a series of earlier " processes of reworking " in Quaternary and earlier ages.

Thus, quartz sands and kaolinite, instead of freshly supplied primary rock dusts, dominate the material of loads in the Amazon river system.

What has been stated above applies to the bed load and coarse particles of suspension load. There are, of course, plenty of materials in solution and very finely dispersed clay minerals which travel for long distance and may, therefore, come from places of origin much farther upstream, e. g., in the Andes mountains.

A slightly different conditions seem to obtain in the State of Maranhão. The Triassic and Cretaceous deposits and also Tertiary deposits derived therefrom are arkosic sediments laid down under apparently more arid conditions, possibly mixed with some amount of volcanic ashes. Thus, sediments in this state appear to contain more feldspathic sands and silts and also montmorillonitic clay.

b. "Rio branco" versus "rio preto" (white river versus black river)

Water of a "rio branco" is sometimes called água amarela (yellow water) and that of a "rio preto", águo azul (blue water).

According to the writer's observations the Rios Xingu, Tapajós, Trombetas, Negro are with água azul, whereas Rios Solimoes, Amazon, Madeira are with água amarela.

Those rivers with água azul are either drowned or half drowned valleys or rivers with large "lakes" before joining the Amazon. That the water emptying into the Rio Amazon from large and small lakes on the "várzeas", through furos or short canals is água azul, is clearly observed from an aeroplane. The waters in these drowned vallyes or lakes get rid themselves of suspended materials during their extremely slow or nearly stagnant motion of flow.

While the main Amazon, etc., running with higher velocity, always gets a new supply of suspended load by their bank erosion.

The difference in the amount of suspended matter, hence the difference in color of water, seems to be partly due to the difference in the motion of water mass.

c. Natural levees

The material with which the natural levees are constructed is usually fine sands and silt. On the bluffs exposed above the low water level, occasional stratification is seen due to alternate deposition of fine sands, silt and clay (downstream of Óbidos).

This is because the natural levee on the concave side has been gradually shifted and invaded the ground where there used to be a lake bottom which received clayey sediments. The top of a levee is always coated with coarser material, that is, fine sands and silt.

In the Rio Trombetas, there is found a very extensive development of "kaolinite levees". Here the river is half drowned and, therefore, has less amount of load of sand size. The kaolinite levees are being built with small pieces of hardened masses of kaolinite plucked below and tossed up by upwelling water along the concave banks. When these small pieces (up to 20 mm) roll over the levees, they either get trapped by the mass of tree rootlets or settle down as the turbulence of water diminishes. That a large amount of kaolinite is being transported also in suspension is known by the thickness of white kaolinite cakes formed on fallen leaves on top and outside slope of the levee.

This kaolinite is supposed to be only a small part of a tremendous deposit of it on the entire lake bottom, which has been re-worked and remodelled into high, parallel "dykes" on the flat lake bottom, that is into natural levees, delineating the course of the stream within the lake.

d. Lake bottom

The sediment on the lake bottom is a bluish grey silty clay. This is a good material for burning tiles. Judging from a nice orange color of the tiles with always brilliant and animating contrast against the green of the jungle,

the material contains a low percentage of iron oxide. This iron content is also known from numerous brown limonite stains along the large and small underground water canals within the mass.

The sands and silt on top of a natural levee merges into bluish gray, silty clay within a distance of a little less than 100 m away from the bank (Rio Sapucaia, 10 km downstream of Monte Alégre).

The silty clay covering the bottom of the Lago Grande, Monte Alégre, becomes a grazing land for cattle during the dry seasons. The ground about 1 m above the low water (but about 3 m below the flood water) dries to a light grey color, and becomes so hard and compact that a truck could drive on it without leaving any prints. This dry land is interrupted by frequent swamps where the water level may be considerably higher than that of the river of paraná.

During the pepiod of flooding, this lake bottom becomes submerged and native rice, canarana, etc. grow on it. The rice grows upward with the flood water and always outgrows it by about 1–1.5 m, finally their stalks reaching 7–8 m long. The half-floating stalks of this thickly grown native rice as well as other plants often block the navigation of canals, but make an excellent habitat for insects, birds and other wild lives.

e. Lake beach

Along the lower Tapajós, the river is drowned to form a lake, about 15 km wide on the average and a little over 100 km long. The lake of água azul is encircled with beautiful beach of white sands, a rare landscape in the muddy várzeas in the Amazon. The white sand beach is about 30 m wide and 5 to 6 m high above the low water level. Sometimes it forms conspicuous sand bars (near Alter do Chão) and, shoals or low islands close to the shore (Prainha).

A similar white sand beaches are observed around lakes along the Trombetas, in the neighborhood of Oriximiná.

These sands are being sorted by waves and transported by currents along the shore, both being caused by strong winds. They are supplied by the Tertiary sandstones cemented by kaolinite which form the bluffs and steep slopes along the gullies immediately on the back of the shores.

These are sands locally washed out of the Tertiary formations and worked by the wave action of the lakes and are not sands transported as bed loads of the Rios Tapajós or Trombetas. The competency of the streams of these rivers is far from being large enough to move these sands, after the water was gradually ponded and approached the present level due to the glacioeustasy, etc.

Sands may also be supplied by Pleistocene terrace deposits, such as those in Monte Alégre and possibly some of the sands around Santarém. In fact, some of the Pleistocene terrace sands are very probably the beach sands of contemporary lakes, esturaries, etc.

Summary

1. The meandering streams of the Amazon river system are active in sub-aquatic erosion on their banks. They are active agencies of planation of the land surface.

2. The regularly repeated cycles of sedimentation as well as the lithologic nature of the Paleozoic, Triassic and Cretaceous formations, deposited in the maritime regions and also in the Amazon "trench" within the continent, indicate secular, epeirogenic movements of the crust, and a long continued planation in the interior of the continent.

The Tertiary formations occupy a low plateau of so-called Amazon Plain which constitutes the floor of the Amazon basin. These are the product of another age of planation.

The mode of distribution of the Pleistocene sediments and frequent drowned valleys—known as the "Amazon rias" by geographers—are the outcome of an entrenchment during the glacial ages, due to the glacio-eustatic regrading of the channels of the Amazon river system. The entrenchment appears to have been particularly effective because of the light load of the rivers during the Pleistocene age (see next paragraph).

3. Quaternary sediments of either glacial tills, aeolian loess or volcanic ashes are not found in the Amazon. These are common sediments that characterize "elevated" floodplains in the great agricultural lands on low sedimentary plains over the world—the pampas of Argentine, the north-central states in U. S. A., North China, Ukraina in U. S. S. R. and northern Europe.

The contrast of floodplains against the Tertiary low plateau, that is, of the "varzeas" against "terras firmes", is usually sharp because of the absence of this kind of "elevated" floodplains in the Amazon.

4. Very sandy top soil, with clay content less than about 30%, can be formed either as residual or sedimentary layers on both highland and lowland.

Wherever these sandy top layers get too dry during dry seasons, grasslands seem to develop over them.

The concentration of annual precipitation in dry and wet semi-annual periods also seems to favor the development of grasslands, e. g. in Amapá, Rio Branco, etc.

A flat top of a plateau is sometimes a grassland, while the adjacent area of its sloping flank is covered with trees and forests, e. g. in Amapá, Goiás, Mato Grosso.

Thus, the forest-grassland boundary seems to be controlled by soil, climatic as well as topograhic factors.

5. The lateritization under the forest results in a deep kaolinitic profile, usually several meters thick, capped with a sandy layer where the parent rock contains quartz—the laterite profile of an incomplete stage. The sandy layer gets thicker on flatland on top of plateaus as well as on foot of hills—the laterite profile of an intermediate stage.

6. When a climate of a tropical savanna type sets in, the forest retreats from

and grasslands take over the flat top of the plateaus. This is due to the decreased water holding capacity of the top sandy layer. Then a zone of limonite concretions begins to grow thicker under the grassland to bring the laterite profile into one of a complete stage.

When a wet climate of an equatorial rain forest type returns, the forest comes back on the grassland and destroys the limonite concretion zone or crust. Therefore, a forest not only prevents a laterite profile from maturing but also can destroy once complete profile.

7. Different rock formations on "terras firmes" give rise to different kinds of weathered products. A diabase gives red soil resembling the so-called terra roxa in the states of São Paulo and Paraná, etc. Some of the Paleozoic illitic shale seem to give a fertile soil, too. Tertiary kaolinite beds give a thick, sticky clayey top soil even on a flat forest land.

8. The modern soil profiles (A, B and C) are superimposed on ancient soil—or laterite profiles of different stages, which are denoted by the writer with A′, B′$_1$ B′$_2$ and C′. The writer proposed the use of a double symbols system to denote the horizons of tropical soils in a superimposed profile: A′ A, A′ B, B′$_1$ C, etc. (XVIII Intern. Geogr. Congr., Rio de Janeiro, 1956).

9. The bauxite deposits in the Amazon seem to be the product of a lateritization under savannas in ages earlier than the Pleistocene.

The large manganese deposit in Amapá seems to be the product of a lateritization under forests which also dates back to ages earlier than the Pleistocene.

10. The sediments on "várzeas" are characterized with dominant quartz and kaolinite. This is true for the Pleistocene and also for the Tertiary sediments. It is due to the long continued, contemporary lateritization, either under savannas or forests, on the flat "terras firmes", and to the lack of the supply of fresh rock dusts of glacial tills, etc. during the Pleistocene age. The writer once stated his wish to call the Amazon basin a "sea of kaolin" because of the overwhelming abundance of this mineral in the basin.

The Cretaceous sediments and also the Tertiary materials derived therefrom in the state of Maranhão seem to contain more feldspathic sands and tuffaceous material and even some amount of active clay minerals of montmorillonite type.

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GEOLOGIC MAP OF THE LOWER AMAZON

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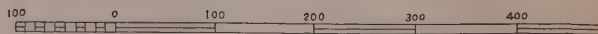
Based on EASTERN SOUTH AMERICA compiled by
Geographical Society, Washington, 1955;
and THE GEOLOGIC MAP OF SOUTH AMERICA, p
The Geological Society of America, New York, 19
boundaries for Paleozoic systems partly revise
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		MIOCENE: BARREIRAS (PARÁ, AMAZONAS)
		PIRABAS (MARANHÃO)
MESOZOIC — CRETACEOUS	Ku	ALTER DO CHÃO (PARÁ, AMAZONAS)
		ITAPECURU, ETC. (MARANHÃO)
MESOZOIC — TRIASSIC	R̄c	RORAIMA (RIO BRANCO)
PALEOZOIC — PERMIAN	M̄c	PEDRA DE FOGO (PARÁ, MARANHÃO)
PALEOZOIC — PENNSYLVANIAN	CNO	NOVA OLINDA (PARÁ, AMAZONAS)
PALEOZOIC — "	CIt	ITAITUBA (" , ")
PALEOZOIC — MISSISSIPPIAN	CMA	MONTE ALEGRE (" , ")
PALEOZOIC — DEVONIAN	DCu	CURUÁ (" , ")
PALEOZOIC — "	DMa	MAICURÚ (" , ")
PALEOZOIC — SILURIAN	STr	TROMBETAS (" , ")
PRECAMBRIAN — LATE PRECAMBRIAN	lpЄ	GURUPI SCHISTS (AMAPA, MARANHÃO)
PRECAMBRIAN — EARLY "	epЄ	GNEISS, GRANITE, SYENITE, ETC.
CRETACEOUS?	MZi	DOLERITE, GABBRO

Ⓒ — PETROLEUM TEST WELL   ⓅAl — ALUMINUM PHOSPHATE DEPOSIT

Ⓜⁿ — MANGANESE MINE   ⟢ — RAILROAD

Ⓕe — IRON ORE DEPOSIT   ⟜ — STATE BOUNDARY LINE

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Paredão

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Vila Nova Ⓕe

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Ilha da Trauira

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Guamá

Macaracunje

L. moeiro

Acará

Xingu

Tocantins

Tomé
Açu

Badajos Ⓒ

lpЄ

São Luiz

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THE CAMBRO-ORDOVICIAN FORMATIONS AND FAUNAS OF SOUTH KOREA, PART VI.

Palaeontology V.

By

Teiichi KOBAYASHI*

With Plates XII–XIV

Contents

Introductory Notes

The geology of the Kangwŏn-do (Kogendo) Limestone Plateau which I late-ly described is the part 4 of this series of publications. However, more than twenty years elapsed since the third part of Palaeontology had been published. During this interval new localities were discovered in the Mun'gyŏng (Bunkei), Tan'gyang (Tanyo) and other areas by SHIRAKI, AMANO, YOSIMURA, IWAYA, HUKASAWA, AOTI and others including myself, and new materials were collect-ed by them. Some of the fossils are however, poorly preserved, while some others are not yet precisely allocated in the stratigraphic sequence. This was one of the reasons that I postponed to monograph them, although many other works interrupted me in this study.

The last paper (1958) containing the description of 7 species of gastropods from Mun'gyŏng district is the part 5 of the Cambro-Ordovician Formations and Faunas of South Korea.

Among the papers which I have published after the third part of pala-eontology the followings deal with the Cambro-Ordovician fossils of South Korea.

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Olenus asiaticus. n. and *Acrocephalina trisulcata,* n. described from near Neietsu.

13. 1949. The *Glytagnostus* Hemera, the oldest world Instant. *Japan. Jour. Geol. Geogr. Vol. 21.*
Describes *Glyptagnostus reticulatus* from north of Neietsu.

14. On *Birmanites,* a Lower Ordovician Genus of Trilobite. *Jour. Geol. Soc. Japan. Vol. 56.*
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15. 1953. On the Kainellidae. *Japan, Jour. Geol. Geogr., Vol. 23.*
Includes descriptions of *Kainella euryrachis,* n. sp., *Pseudokainella iwayai,* n. sp., *Pseudokainella* a. sp., *Pseudokainella* (?) b. sp., *Hukasawaia,* n. g. of *Richardsonella, Hukasawaia cylindrica,* n. sp. and *Apatokephalus hyotan,* n. sp.

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Describes *Kingstonia parallela, Plethometopus longispinus, Iddingsia orientalis, Berkeia shantungensis, Hamashania* (?) sp.

19. 1958. On Some Cambrian Gastropods from Korea. *Japan. Jour. Geol. Geogr. Vol. 29.*
Hampilina goniospira described from Mun'gyŏng district.

20. 1958. Some Ordovician gastropods from the Mun'gyŏng or Bunkei District, South Korea. *Jour. Fac. Sci. Univ. Tokyo, Sect. 2, Vol. 11, Pt. 2.*
Describes " *Bellerophon* " *aotii,* n. sp., *Scalites irregulare,* n. sp., *Helicotoma amanoi,* n. sp. and some other species.

The Cambrian and Ordovician Faunas of South Korea described in the Parts 1–3 in 1934–35 were mostly procured from the strata on the southeastern side of the limestone plateau, in the sequence of which is now known by the name of the Tsuibon type. It is quite distinct from that of the axial part of the Yokusen folded mountains. The so-called *Olenoides* zone of Neietsu, however, has been the sole fossil bed in the Neietsu anticlinorium known before 1935.

Intensive investigations were repeated from 1938 to 1940 by I. YOSIMURA and T. HUKASAWA jointly with me. As a result copious faunas were found at many localities in various horizons and the Cambro-Ordovician sequence of the Neietsu type was classified as follows:

The Middle Ordovician Eiko formation.
The Lower Ordovician Bunkoku formation.
The Upper Cambrian Gakoku formation.
The Upper and Middle Cambrian Machari formation.
The Middle Cambrian Samposan formation.

The base of the Samposan is unexposed. A few graptolites discovered by HUKASAWA from the Bunkoku formation were described in 1942 by KIMURA and myself; a few trilobites from the Bunkoku and Machari formations also described by me on some occasions. It is aimed here to figure the whole picture of the Gakoku and Bunkoku faunas and, at the same time to supple-

ment some notes to the Ordovician fauna in the Tsuibon zone.

Anatifopsis is indeed a new find outside Europe. On this occasion the Trilobite classification is briefly reviewed and my view added. A precise stratigraphic description of the Bunkoku and Gakoku formations and a detailed discussion on their faunas are, however, deferred to a later occasion.

Here I wish to record my sincere thanks to Dr. G. A. Cooper of the U. S. National Museum, Wanshington, D. C. for sending me the plaster casts and photographs of the holotypes of *Dikellocephalus flabellifer* Hall and Whitfield and *D. multicinctus* Hall and Whitfield.

Formation and Localities

The Gakoku formation is chiefly composed of dolomitic limestone, but chert layers are intercalated in the lower part. Fossils are very rare in it. Brachiopods and trilobites which were obtained at the following four localities, all in Yŏngwŏl-gun, Kangwŏn-do, are poorly preserved. The *Apheoorthis* faunule is proposed for them because of the superiority in the number of specimens.

Loc. 253. Northwest of Nŭng-dong, Yŏngwŏl; Ryodo Decke.
　　　　　寧越面陵洞北西
Loc. 262. Southwest of Nŏl-tari, Puk-myŏn; Machari Decke.
　　　　　北面磨礎里南西，磨礎里共同墓地の山
Loc. 263. Southwest of Mach'a-ri, Puk-myŏn; Chikari Decke.
　　　　　北面磨礎里南西
Loc. 275. Southwest of Kok-kol, Puk-myŏn; Machari Decke.
　　　　　北面谷洞南西

Apheoorthis ranges in North America from Upper Cambrian to Basal Ordovician or Upper Ozarkian by Ulrich and occurs commonly in the Cordilleran province. Because the Gakoku formation lies between the Machari formation and Lower Ordovician Bunkoku formation and because the Machari yields *Olenus* in the upper part, the Gakoku must be medieval and late Upper Cambrian in age.

The Bunkoku formation consists of limestone, limestone-conglomerate, marl and shale in alternation. *Yosimuraspis* is ubiquitous in the dolomitic limestone in the basal part which contains *Asaphellus* in rare instances (ex. Loc. 289). Hence the name *Yosimuraspis* beds. *Yosimuraspis* is, however, absent in the beds which bear various other fossils. The fossil localities of the formation are as follows:

Yosimura collection. (Y: *Yosimuraspis* zone)
Loc. 206. 14 km. NNE of Chŭng-san, Puk-myŏn; Machari Decke.
　　　　　北面甑山北北東
Loc. 221. East of Namae-ri, Puk-myŏn; Chikari Decke.
　　　　　北面南崖里東方
Loc. 232. East of Mungong-ni, Puk-myŏn; Nangairi Decke.
　　　　　北面文谷里東方
Loc. 233. West of Chŭng-san, Puk-myŏn; Chikari Decke.
　　　　　北面甑山西方

Locs. 234–236. (Y), West of Chŭng-san, Puk-myŏn ; Chikari Decke.
　　　　北面甑山西方

Locs. 238–240. West of Chŭng-san, Puk-myŏn ; Chikari Decke.
　　　　同　　　　上

Loc. 247. Munp'ori, Puk-myŏn, Yŏngwŏl-gun, Nangari Decke.
　　　　北面文浦里

Locs. 248–249. West of Chŭng-san, Puk-myŏn ; Chikari Decke.
　　　　北面甑山西方

Locs. 250–252. Highway at Mohari, Puk-myŏn ; Chikari Decke.
　　　　北面茅下里自動車路

Loc. 266. Noŭn-tong, Puk-myŏn ; Chikari Decke.
　　　　北面老隠里

Loc. 272. (Y), 500m. West of Changsong-gok, Moha-ri, Puk-myŏn ; Nangairi Decke.
　　　　北面茅下里獐成谷西方 500 米

Loc. 277. (Y), SW of Kok-kol, Puk-myŏn ; Machari Decke.
　　　　北面谷洞南西

Loc. 282. Kok-kol, Puk-myŏn ; Macahri Decke.
　　　　北面谷洞

Loc. 289. (Y), West of Karae-gol, Puk-myŏn ; Nangairi Decke.
　　　　北面楸洞西方

HUKASAWA collection.

Yosimuraspis zone.

Loc. 01907. East of Umji, Chongbu-ri, P'yongch'ang-myŏn.
　　　　平昌面鐘阜里陰地東方

Loc. 91602. 500 m. saddle of Paeil-ch'i, Paeg'un-dong, Mungong-ni, Puk-myŏn.
　　　　寧越北面文谷里白雲洞拝日峙

Loc. 91603. 2 km. northwest of Loc. 91602.
　　　　Loc. 91602 の北西 2 粁

Loc. 91902. East of Tŏksang-ni, Puk-myŏn.
　　　　北面德上里東方

Loc. 91903. North of Tŏksang-ni, Puk-myŏn.
　　　　北面德上里北方

Loc. 91904. Saman, Toksang-ni, Puk-myŏn.
　　　　北面德上里沙湾

Loc. 91905. 300 m. west of the pass of Saman, north of Toksang-ni, Puk-myŏn.
　　　　北面德上里北方沙湾へ行く峠の西下 300 米

Loc. 92005. East of Sajong-ch'i, Ongjŏng-ni, Sŏ-myŏn.
　　　　西面瓮亭里射亭山峙東方

Loc. 92007. P'ong-dong, Puk-myŏn.
　　　　北面坪洞

Loc. 92101. NNE of Puksang-ni, Sŏ-myŏn.
　　　　西面双里北北東

Loc. 100102. South of Wŏn-dong, southwest of San'yŏngwŏl, Puk-myŏn.
　　　　北面山霊月南西，院洞南方

Loc. 100906a. West of Myŏngna-gok, Sanae-ri, Sŏ-myŏn.
　　　　西面新川里鳴羅谷

Higher beds.

Loc. 91405. Paeg'un-dong, Puk-myŏn.
　　　　北面白雲洞

Loc. 92002. Boulder at Hwapyŏng at the foot of the pass to Puksang-ni, Ongjong-
　　　　ni, Sŏ-myŏn.
　　　　西面瓮亭里北双里へ行く峠の麓 花屏の転石

Locs. 92902–92903. 2 km. south of Kal-kol, Puk-myŏn.
　　　　北面蘆洞南方 2 粁

Loc. 92906.   1 km. east of Yongso-gol, southwest of Kal-kol, Puk-myŏn.
                北面鱼洞東方1料
Locs. 93002-93004.   Mudong-gol, Yongong-ni, Puk-myŏn.
                北面延德里舞童谷
Loc. 100101.   South of San'yŏng-wŏl, west of Yondong-ni, Puk-myŏn.
                北面延德里西方山霊月の南
Loc. 100903.   West of Pae-Maul, Sŏ-myŏn.
                西面舟村西方
Loc. 100906b.   See 100906a.
Loc. 101110.   North of Ap'asil, Mai-ri, P'yongch'ang-myŏn.
                平昌面馬池里阿波実北方
Loc. 101909,   SSE of Umji, Chongbu-ri, P'yongch'ang-myŏn.
                平昌面鐘阜里陰地南南西

The main Bunkoku fauna which is contained in the formation above the *Yosimuraspis* zone is a copious one as shown in the table on page 225. In the Tsuibon type of sequence *Lingulella tomkolensis Micragnostus coreanicus* and *Asaphellus tomkolensis* occur in the lower or *Asaphellus* zone, *Shumardia pellizzarii*, *Protopliomerops punctatus*, *Metapilekia martellii* and *Plumulites primus* in the middle or *Protopliomerops* zone and *Pomatotrema shinsoensis*, *Koraipsis spinus* and *Hystricurus megalops* in the upper or *Clarkella* zone.

In the type section of the Bunkoku formation the fossil localities 238, 239, 240, 248, 249 and 233 are aligned from the lower to the upper horizon. *Apatokephalus hyotan*, *Asaphellus tomkolensis* and *Anatifopsis cocaban* are vertically long-ranged and *Asaphellus tomkolensis* is found together with *Shumardia pellizzarii* and *Hystricurus megalops* in the highest horizon in the section. At Loc. 252 *Micragnostus coreanicus* and *Asaphellus tomkolensis* are accompanied by *Protopliomerops punctatus* and *Pomatotrema* cfr. *shinsoensis*. Thus the vertical distribution of these species is somewhat different from that found in the Tsuibon sequence. Nevertheless, it is certain that the Bunkoku fauna can be correlated on the whole to those of the Tomkol and lower Makkol formations. The Lower Ordovician age of the Bunkoku fauna is further endorsed by the inclusion of *Apatokephalus*, *Dikelokephalina*, *Metapilekia*, *Hintzeia*, *Anatifopsis* and *Dictyonema* cfr. *flabelliforme*.

Beside these *Palaeacmaea* (?) sp., *Clarkella vulgaris* and *Ribeirella subcircularis* were procured by YOSIMURA from Loc. 193 which is presumably located in the *Clarkella* zone at a point about 1 km. to the east of Yemiri, Sangdong-myŏn, Yŏngwŏl-gun, Kangwŏn-do, 江原道寧越郡上東面礼美里東方 1 粁.

In addition, some fossils described here belong to SHIRAKI's collection from two localities in the Tomkol shale on the north and south wings of the Hakunsan syncline as follows:

Shi-2.   NNE. of Chamiwŏn, Nam-myŏn, Chŏngsŏn-gun, Kangwŏn-do.
                江原道旌善郡紫味院北北東
Sei-14.   About 800 m. north from the branching point of roads between Sosa-gok and Ch'ojon-chon, Sangdong-myŏn, Yŏngwŏl-gun, Kangwŏn-do.
                江原道寧越郡上東面沙谷・草田村間道路

Finally, some comments are given on a few fossils from the Tomkol shale at the following localities which are already described in Part 3.

Locality	Yosimura's Collection — Type Section															Hukasawa's Collection							Collection				
	238	239	240	248	249	233	206	221	232	247	250	251	252	265	266	91405	92002	92902	92903	92906	93002	93004	100101	100906	100903	101909	101110
1. Lingulella tomkolensis		(×)		×														×									
2. Pomatotrema (?) sp.										×		×													×		
3. Hyolithes (?) sp.				×	×																						
4. Micragnostus coreanicus				×	×	×							×		×												×
5. Shumardia pellizzarii																											
6. Hystricurus megalops			×															×	×	×						×	
7. Hukasawaia cylindrica																											
8. Pseudokainella a sp.								×																			
9. Aotiaspis sp. indt.								×																			
10. Apatokephalus hyotan	×	×		×	×	×					×		×	×													
11. Dikelokephalina parva																		•									
12. Dikelokephalina conica																											
13. Asaphellus tomkolensis		×		×	×	×	(×)	×					×	×													
14. Metapilekia sp. nov.									×																		
15. Protopliomerops punctatus											×		×														
16. Koraipsis spinus								×																			
17. Hintzeia glabella																											
18. Pliomerid, thorax, gen. indt.																											
19. Anatifopsis cocaban		×	×	×			×	×			×		×								×			×			
20. Anatifopsis truncatum												×	×									×		×			
21. Cystoid, indt.																											
22. Plumulites cfr. primus																											
23. Plumulites sp.																											
24. Dictyonema cfr. flabelliforme																×										×	
25. Clonograptus (?) sp.																×										×	
26. Coprolites (?)																							×			×	

The Bunkoku Fauna (exclusive of the fossils from the *Yosimuraspis* zone)

Doten: Tongjom-ni, Sangjang-myŏn, Samch'ok-gun, Kangwŏn-do.
                江原道三陟郡上東面銅店里
Makkol: Makkol, Sangdong-myŏn, Yŏngwŏl-gun, Kangwŏn-do.
                江原道寧越郡上東面莫洞
Saishori: Sesong-ni, Sangdong-myŏn, Yŏngwŏl-gun, Kangwŏn-do.
                江原道寧越郡上東面細松里
Tomkol: Tumu-kol, Sangdong-myŏn, Yŏngwŏl-gun, Kangwŏn-do.
                江原道寧越郡上東面斗務洞

Description of Fossil

One new family, five new genera, twelve new species and one new sub-species instituted through this paper are as follows:

Birmanitidae
Aotiaspis
Dainellicauda
Girvanopyge
Hederacauda
Yosimuraspis
Anatifopsis cocaban
Anatifopsis truncatum
Apheoorthis orientalis
Aotiaspis oblonga
Aotiaspis ovalis
Dikelokephalina conica
Dikelokephalina parva
Hintzeia glabella
Hystricurus calvus
Micragnostus coreanicus
Ribeirella subcircularis
Yosimuraspis vulgaris
Yosimuraspis vulgaris longulum

Some remarks are given on the Dikelocephalidae, Geragnostidae, Monkaspidae, Ribeiridae, Richardsonellidae, Teihungshaniidae, a few subfamilies, several genera and Upper Cambrian asaphids.

Phylum Brachiopoda

Class Inarticulata

Order Atremata.

Family Obolidae KING

Genus *Lingulella* SALTER, 1866

Lingulella tomkolensis KOBAYASHI, 1934

Plate II, Figures 12–13.

1934. *Lingulella tomkolensis* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 3, Pt. 9*, p. 527, pl. 3, fig. 4.

Dorsal valve nearly parallel-sided; lateral margins slightly arcuate, abruptly bent toward anterior margin which is also nearly straight; posterior margin forms an obtuse angle; ventral valve much longer than the dorsal; umbonal area protruded, forming an acute angle at the beak.

Occurrence:—Bunkoku Formation at Loc. 258; *Asaphellus* zone at Tomkol and Dotenri.

<center>Class Articulata</center>

<center>Order Protremata</center>

<center>Family Billingsellidae Walcott and Schuchert, 1908</center>

A small collection from the Gakoku formation contains at least three kinds of protremate brachiopods. Little, however, is known of either the cardinal area or musculature except for a dorsal valve of *Eoothis* (?) sp. indt. in which the deltidium is absent. Surface ornaments of *Apheoorthis orientalis* is typical of the genus.

<center>Genus *Eoothis* Walcott, 1908</center>

<center>*Eoorthis* (?) sp. indt.</center>

<center>Plate XII, Figures 5-6.</center>

Shell a little broader than long and gently convex. The dorsal valve in fig. 5 has a broad obtuse umbo where ornamentation is obscure. Near the margin, however, there are many radial ribs of similar strength which are separated from one another by narrow and deep furrows. Fine numerous concentric lines are impressed on the ribs.

Another dorsal valve in fig. 6 shows well developed interareas, large triangular delthyrium without a deltidium but a spondylium of moderate size is present; no distinct vascular trunks as in *Billingsella* seen on the valve.

Occurrence:—Gakoku formation at Locs. 253 and 276.

<center>Genus *Apheoorthis* Ulrich and Cooper, 1936.</center>

<center>*Apheoorthis orientalis* Kobayashi, new species</center>

<center>Plate XII, Figure 2.</center>

Description:—Shell small, gently convex; ventral (?) valve two-thirds as long as wide, scarcely alate at hinge margin; mesial sinus narrow and very shallow; umbo a little projected above the margin; growth lines strongly impressed at regular intervals. In the median part are 4 ribs and 4 or more riblets in each interval, but the difference of prominence between the ribs and riblets is reduced laterally.

Comparison:—The fasciculate ornamentation is an important external dis-

tinction of *Apheoorthis* from *Eoorthis*, s. str. The plication is not so sharp in this species as in *Apheoorthis ocha* (WALCOTT) and *A. meeki* ULRICH and COOPER. *Eoothis shakuotunensis* SUN and *E. pagodiformis* KOBAYASHI have the same kind of ornamentation, but the fineness of the ornaments shows that these species are closer to *A. ornata* and *A. melia* than this species.

Occurrence:—Bunkoku formation at Loc. 253.

Apheoorthis (?) sp. indt.

Plate XII, Figures 3–4.

Shell almost twice broader than long, multicostellate, but not fasciculate at the preceding; hinge line a little shorter than the maximum breadth; radials increase their number by forking; concentric growth markings well impressed with short intervals. Ventral valve gently convex, somewhat flattened in medio-ventral part, but scarcely sulcate; dorsal valve strongly convex near umbo which is projected above hinge margin and somewhat incurved.

This resembles *Apheoorthis emmonsi* ULRICH and COOPER, but its outline is more transversal and the umbo of the dorsal valve larger and more prominent.

Occurrence:—Bunkoku formation at Locs. 253–262.

Family Deltatretidae SCHUCHERT and COOPER, 1931

Genus *Pomatotrema* ULRICH and COOPER, 1932

Pomatotrema (?) sp.

Two external moulds of dorsal valve, though poorly preserved, resemble *Pomatotrema shinsoensis*, but smaller and about 6 mm. wide.

Occurrence:—Bunkoku formation at Locs. 247 and 252.

Family Clarkellidae SCHUCHERT and COOPER, 1931

Genus *Clarkella* WALCOTT, 1908

Clarkella vulgaris KOBAYASHI

Plate XIV, Figure 1.

1934. *Clarkella vulgaris* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec., 2, Vol. 3, Pt. 9*, p. 530, pl. 2, figs. 11–18.

A ventral valve agrees with the valve in fig. 11, pl. II, 1934, in outline and the size of the median sinus, although the convexity of the valve appears a little stronger in the present valve than in that specimen.

Occurrence:—Loc. 193 with *Ribeirella subcircularis*.

Phylum Mollusca CUVIER

Class Gastropoda CUVIER

Family Tryblidiidae PILSBRY, 1899

Genus *Palaeacmaea* HALL and WHITFIELD, 1782

Palaeacmaea (?) sp. indt.

Plate XIV, Figure 4.

Shell very low patelliform; aperture broad, ovate in outline; apex small, at about one-fourth of shell length from the anterior. The aperture is about 3 mm. broad and 4 mm. long. Only the internal view is allowed to the observer. It is broad undulated and a few such undulations radiate from the apex to the broad posterior margin. Beside them, there are very fine radial and concentric striae.

Although the upper surface is invisible, the apex is presumed to be somewhat acuminate. The anterior slope may be more or less concave. The lateral and posterior slopes are flattish. However, a broad low internal elevation extending backward from the apex in the apertural view must be a large depression. There is no indication for rugose folds or terraces as seen in *Scenella*, *Palaeacmaea* or *Helcionella*. With such a specimen it is difficult to determine its taxonomic position.

Occurrence:—Loc. 193 with *Clarkella vulgaris*.

Mollusca (?) Incerta Sedis

Family Hyolithidae NICHOLSON

Genus *Hyolithes* EICHWALD, 1840

Hyolithes (?) sp. indt.

Plate XIII, Figures 22 a–b.

An internal mould of an operculum (?) consists of a subcircular main plate and subquadrate dorsal (?) projection. The plate is slightly longer than broad, and forms an obtuse angle at the median point of the dorsal margin. The mould rises up toward this point and two obtuse carinae extend ventrally from this point, dividing the subcircular plate into three areas of subequal size. The subquadrate part is represented by a deep depression which is somewhat expanded from the subcircular plate and truncated by the straight dorsal margin. It is bisected by a thick axial wall which extends from the dorsal margin. Because this specimen is an internal mould, it must have been a profound groove. Ignoring the subquadrate projection, this fossil reminds me of an operculum of hyolithid. I know no comparable fossil in which the two parts are combined. It appears to hold bilateral symmetry, but there is a small process at about the middle of the left dorsal margin of the main part, but not on the other side. No hyolithid shell is as yet found from the Bunkoku formation. Therefore it is probable to belong to an unknown animal quite unrelated to *Hyolithes*.

Occurrence:—Bunkoku formation of Loc. 249.

Phylum Arthropoda

Class Trilobita WALCH

In 1897 BEECHER has proposed Hypoparia, Opisthoparia and Proparia for his scheme of Trilobita Classification. It was certainly epoch-making, but its validity was soon questioned by POMPECKJ in the next year. On the basis of the ontogenetical study BEECHER laid special stress on the eyes and facial sutures in his classification, but the heterogenity of the Hypoparia was exemplified by REED (1898) in his paper on blind trilobites (1898). POULSEN's Intergricephalida (1927) in which most hypoparian families are combined with the Conocoryphidae are no less heterogeneous than the Hypoparia. SWINNERTON (1915) ignored the Hypoparia, but accepted the view that the Proparia are more advanced than the Opisthoparia. POULSEN (1923) found that *Peltura scaraboeoides* is proparian in the early meraspid stage. RICHTER (1932) considered that the Proparia are more primitive than the Opisthoparia. Thus BEECHER's classification was modified in fundamental lines. Nevertheless, the Opisthoparia or the other taxon was maintained by some authors as valid for about a half century, but completely neglected in the modern classifications by WHITEHOUSE (1936, 39), HENNINGSMOEN, HUPÉ, HARRINGTON et al. (1959) and some others.

It was in 1935 that I have concluded the polyphyletism of not only the Hypoparia but also the Proparia, in pointing out the fact that the Cambrian proparians have little relationship among themselves as well as to the later proparians. The invalidity of the Proparia was immediately vindicated by the discovery of proparian olenids in the Lower Ordovician of Argentina which are, however, by no means ancestral to other proparian trilobites. It was my conclusion in 1935 that, although the facial suture is one of important criteria, the natural classification must be founded on the combination of evolutional characters, and that not only morphological and ontogenetical evidences, but also the specio-temporal distribution should be brought into account for the evolution of trilobites.

The parallelism of the trilobite evolution among the Older Palaeozoic zoopalaeogeographic provinces was then exemplified. The Damesellidae (1941-42) and some other families which flourished in Asia or the Pacific province were later revised in detail. It was further pointed out in 1935 that at least four groups of trilobites have already existed in the early Cambrian period which indicate the palaeontological stocks. The pre-Cambrian divergence of these stocks is prepalaeontological, or something what cannot be documented with fossils. From this viewpoint the Agnostida, Mesonacida (or Redlichida), Corynexochida and Ptychoparida must be recognized as four primary orders. The Dikelocephalida was added to them as a secondary order by the reason that its derivation either from the Corynexochida or Ptychoparida was indecisive at that time, although the latter alternative was subsequently found veritable (1936).

In 1936 STUBBLEFIELD concluded the polyphyletism of the Proparia, noting that proparian condition may be regarded as arrested development. WHITEHOUSE

(1936, 39) on the other hand distinguished seven discrete Lower Cambrian groups, namely the Mesonacida, Conocoryphida, Ptychoparida, Ellipsocephalida, Corynexochida, Agnostida and Eodiscida. He combined the last two into the Miomera and placed the remainder in the Polymera.

Prior to this Gürich (1907) combined the Agnostidae with the Microdiscidae (or Eodiscidae) in the Isopyga of the Oligomera, while Jaekel (1909) divided trilo- bites into the Miomera and Polymera. The opinions of the two authors agreed in laying special weight on the number of thoracic segments, but they are opposed in that the former regarded the Isopyga to be primitive whereas the latter took the Miomera for the advanced group.

Intensive studies have been repeated on the miomeric trilobites in last century by various authors. While Resser (1938) segregated the agnostids out of the Trilobita inclusive of eodiscids, I have emphasized in my monographs on the agnostids (1939) and the eodiscids (1944) that the Agnostida comprising eodiscids and agnostids constitute a solid and highly specialized group of the Trilobita.

As for the polymeric trilobites the taxonomy and phylogeny were especi- ally confused for Cambrian genera and families. Therefore I have carried out a preliminary study on them. Although very tentative, I proposed my scheme of classification in 1935. Some of the new families were later investigated in greater details. Many new genera and families were erected by many authors with the materials from Siberia, Central Asia, North Africa, South America and other little known territories. Trilobite morphology and ontogeny were greatly improved in a quarter of this century by sectioning of rolled specimens or etching of silicified materials. Rasetti (1952) distinguished 7 types of ventral cephalic sutures among the early Cambrian trilobites to which two new types were added in the Upper Cambrian. The existing knowledge on the ventral morphology is, however, still limited to a small number of genera.

Taking the olenellid anaprotaspids for the incipient form, Størmer (1948) tried to explain the evolution of the sutures by partial neoteny. He adapted Protoparia for the Olenellidae, instead of the Marellidae for which the term had originally been proposed by Swinnerton (1915). The three other orders were Beecher's. Størmer was, however, not quite convinced himself of the va- lidity of the Hypoparia. At the same time his Proparia comprising the Eo- discidae, Norwoodidae, Burlingidae and Phacopidae cannot be a natural group (Kobayashi and Kato, 1951). Recently Whittington (1957) noted that the smallest larva so far known of the olenellids is already in the meraspid stage.

Paying special attention to the glabellar outline and furrows Henningsmoen (1951) discussed the relationship among the trilobite-families. Thus he reco- gnized 12 superfamilies and concluded that most of the superfamilies are de- rivatives from the Conocoryphacea except for the Agnostacea, Redlichacea, Olenellacea and Zacanthoidacea which indicate isolate branches. Hupé (1925-55) revised the relationship more extensively and precisely and grouped trilobite families into 24 superfamilies most of which were referred to the Polymera except the Eodiscoidae and the Agnostoidae in the Miomera. His Polymera or

Henningsmoens's Conocoryphacea group is a large waste basket which ought to be set to rights. Such an arrangement was undertaken by Harrington et al. (1959) and the Trilobita are schematized into 7 orders in addition to several suborders. It is surprising for me to find in this classification that my prediction was not much deviated from it as below.

Treatise, 1959	Kobayashi, 1935
Agnostida Kobayashi	Agnostida
Redlichiida Richter	Mesonacida (Redlichida)
Corynexochida Kobayashi	Corynexochida
Ptychopariida Swinnerton	Ptychoparida
Ptychopariina Richter	
Asaphina Salter	Dikelocephalida (Ptychoparid branch, 1936)
Illaenina Jaanusson	Proetacea (Ptychoparid branch, 1935
Harpina Whittington	Harpedacea (ditto)
Trinucleina Swinnerton	Trinuclacea (ditto)
Phacopida Salter	
Phacopina Struve	Phacopacea (unknown derivation)
Cheirurina Harrington	⌈Cheiruridae (ditto)
and Leanza	⌊Encrinuridae (ditto)
Calymenina Swinnerton	Calymenacea (Ptychoparid branch)
Lichida Moore	Lichadacea (from Mesonacid, (?) Zacanthoidae)
Odontopleurida Whittington	Odontopleuridae (ditto)

The two classifications coincide with each other in the following fundamental lines :

1. The four primary orders which appeared in the early Cambrian.
2. The Dikelocephalida or Asaphina and all superfamilies which were considered Ptychopariid-branches are recognized as suborders of the Ptychopariida except the Calymenacea.
3. In addition to the Calymenacea, Post-Cambrian families and superfamilies of which origin was unknown or which were presumed derivatives from the Redlichiida throught the Zacanthoididae are accepted as secondary orders or suborders.

Incidentally, whether the Calymenacea are really more related to the Cheirurina than the Ptychopariida may be a matter of moot discussion. There are of course various differences between these classifications with regards to the families involved in these orders. It is my opinion that the major configuration of the cephalon or the whole shield may not be the less important than certain specified criteria of the glabella or cephalic sutures. It requires more and more studies to settle such details. For their solution, I think, much is expectable to the future studies on Pacific or Asiatic materials because many questions attached to the families which have flourished in the Asiatic or Pacific province.

In my opinion Jaekel's bipartation must be accepted in a higher rank than the order, because except for a few probable exceptions, all trilobites have either

bi- or tri-segmented thoraces, or five or more segments in thorax, the fact showing the Pre-Cambrian divergence to be much greater between the Miomera and Polymera than among the polymeric orders.

Reconsidering with the new facts, the scheme of classification is here revised and, though still tentative, it is shown below.

Class Trilobita
    Subclass Miomera
        Order Agnostida
            Suborder Agnostina
            Suborder Eodiscina
    Subclass Polymera
    —Primary orders and suborders—
        Order Redlichiida
            Suborder Olenellinae
            Suborder Redlichiina
        Order Corynexochida
        Order Ptychopariida
            Suborder Ptychopariina
    —Secondary orders and suborders—
            Suborder Burlingina
            Suborder Dikelocephalidina
            Suborder Asaphina
            Suborder Illaenina
            Suborder Calymenina
            Suborder Harpina
            Suborder Trinucliina
        Order Phacopida
            Suborder Phacopina
            Suborder Cheirurina
        Order Lichida
            Suborder Lichina
            Suborder Odontopleurina

Subclass Miomera JAEKEL, 1909

Order Agnostida KOBAYASHI, 1935

Family Geragnostidae HOWELL, 1935

As noticed by HOWELL (1935), the morphic variation among geragnostids and micragnostids is gradual. Therefore it may be too far going to separate them in the family rank. However, they constitute the largest agnostidian group in the Upper Cambrian and Ordovician periods. Therefore it may appropriate to accept *Micragnostus*, *Anglagnostus*, *Corrugatagnostus*, *Geragnostella* and *Girvanagnostus* as five genera of the Geragnostidae, instead of subgenera of *Geragnostus* as done in my revision (1939).

It is certain that *Rudagnostus* Lermontova and *Eurudagnostus* Lermontova which were respectively founded on *Agnostus princeps* var. *rudis* Salter and *Eurudagnostus grandis* Lermontova belong to the same family, because the former species was once referred to *Micragnostus* and the latter is a micragnostid having subcircular shields, each having a pair of well developed posterior spines. It is, however, a question whether the family can safely hold *Homagnostoides* and *Hyperagnostus* whose axial lobe of the pygidium is extraordinally developed for the family.

<p style="text-align:center">Genus *Micragnostus* Howell, 1935</p>

<p style="text-align:center">*Micragnostus coreanicus* Kobayashi, new species</p>

<p style="text-align:center">Plate XIII, Figures 7–11.</p>

1934. Comp, *Agnostus*, a sp. Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9*, p. 537, pl. 3, figs. 2–3.

Description:—Cephalon subquadrate, as long as wide; anterior outline rounded; marginal rim and furrow narrow and running below the cheek rolls in the posterior of lateral sides; shield inside the furrow strongly convex; glabella prominent, subconical, but rounded in front, outlined by deep dorsal furrows, and bilobed by a strong transverse furrow; anterior lobe one-third as long as posterior one which carries a median tubercle; basal side-lobe very small and triangular; posterior rim outside this lobe pointed back.

Pygidium subquadrate, provided with a thick rim which is pointed at a pair of short posterior spines; marginal groove well developed; axial lobe large, strongly convex, elevated above pleural slope, surrounded by deep furrows and composed of two short anterior lobes and a long posterior one; the latter longer than the combined length of the two anteriors; a prominent median ridge lies on the anterior lobes.

Comparison:—This is diagnostic of the genus. *Agnostus chiushuensis* Kobayashi, 1931, is another typical *Micragnostus* common in the Chiushukou shale in South Manchuria. The axis, especially that of the pygidium, is larger in this than in that species.

Among the three Ordovician agnostids in South Korea the nearest is *Agnostus*, a sp. from the *Asaphellus* zone of Makkol, although the cephalon is longer, the marginal rim thicker and the basal side-lobe larger.

As Troedsson (1937, p. 31) states that "it will hardly be possible to distinguish our Central Asiatic form (i. e. *Geragnostus kobayashii* Troedsson from Kobayashi's *Agnostus* a sp.," they look alike, but the glabella is evidently more slender in the Tienshan species. The axial lobe of the pygidium is pointed back in that species.

Occurrence:—Bunkoku formation at Locs. 248 and 252.

Subclass Polymera JAEKEL, 1909

Order Ptychopariida SWINNERTON, 1915

Suborder Ptychopariina SWINNERTON, 1915

Family Shumardiidae LAKE, 1907

Genus *Shumardia* BILLINGS, 1865

Shumardia pellizzarii KOBAYASHI, 1934

Plate XIII, Figures 23-25.

1934. *Shumardia pellizzarii* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3,*
Pt. 9, p. 538, pl. 7, fig. 11a.

Cephalon relatively long; glabella very broad; frontal lobe not much expanded laterally, truncated or even somewhat sinuated in front; posterior lobe parallel-sided; lateral furrows in two pairs, short or indiscernible; transverse furrows between these lobes discrepant on axis; dorsal furrows broad on lateral sides of posterior lobe; neck ring clearly defined by a furrow.

Thorax composed of 6 or 7 segments; axial rings broader than pleurae; fourth pleura prolonged backward into a long spine.

Pygidium short; axial lobe broad, strongly convex, composed of three rings and a terminal lobe; pleural lobe narrow and divided into 4 ribs; marginal rim narrow but distinct; posterior margin somewhat sinuated.

In the specimen in fig. 25 the seventh segment appears to belong more probably to the thorax than the pygidium.

This species is a member of the *pusilla* group. Its cephalon bears the specific characteristics. Rows of granules seen on the thorax and pygidium of *S. pusilla* are apparently absent.

Occurrence:— Bunkoku formation at Locs. 249 and 101110; *Protopliomerops* zone at Saishori.

Family Solenopleuridae ANGELIN

Genus *Hystricurus* RAYMOND, 1913

Hystricurus megalops KOBAYASHI, 1934

Plate XIII, Figure 20.

1934. *Hystricurus megalops* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3,*
Pt. 9, p. 540, pl. 6, figs. 8-9.

An imperfect crandium from Loc. 233 is diagnostic of this species in the pustulate test, ovate concave glabella, weak posterior furrows, deep dorsal furrows, relatively narrow fixed cheeks and large posterior eyes as judged from their broken parts. *H. eurycephalus* can be easily distinguished from this by the outline of the glabella and much finer granules of the test. Furthermore, the anterior facial sutures are not so widely divergent.

*Occurrence:—*Bunkoku formation at Locs. 233, 9202, 92903 and 92906.

Hystricurus cfr. *megalops* KOBAYASHI, 1934

Plate XIII, Figure 21.

This is the first example of a hystricuroid pygidium found in Korea. Its outline is lenticular, attaining the maximum width at the mid-length where the width corresponds about twice the length. The rachis is as wide as a pleural lobe, conical, strongly convex, elevated above the latter and composed of four rings and a small terminal lobe; pleural lobe gently convex, divided into four ribs by furrows; marginal rim narrow, but more or less thickened toward the rear end.

There is no other genus but *Hystricurus* in the Bunkoku fauna which would have this pygidium. Unfortunately the test is weathered and the characteristic pustulation which warrants its identification with the preceding cannot be seen.

Occurrence:—Bunkoku formation at Loc. 240.

Hystricurus calvus KOBAYASHI, new species

Plate XIV, Figures 5-6.

A small hystricuroid cranidium having a long ovate, strongly convex, unfurrowed glabella, distinct occipital furrow, occipital ring carrying a median tubercle pointed behind, and a thick eye-band fairly large, located somewhat posteriorly and disconnected from the glabella by a narrow fixed cheek. No eye-ridge; dorsal furrow distinct and joins its fellow at the median point of the rounded glabellar front whence the axial furrow extends forward. The frontal limb is relatively large, gently convex, inclined distally and separated from a narrow, wire-like rim by a furrow.

An associated free cheek which may belong to this species has a strongly convex ocular platform which elevates toward the large eye and is separated from the marginal rim by a deep groove; genal spine short, extending back without forming an angle with the lateral border.

Facial suture anterior to eye runs obliquely from eye and diagonally crosses the border; that posterior to eye cutting articulating margin shortly inside the genal spine.

This may be an aberrant form of *Hystricurus*, s. 1. Its specialities are the smooth test, relatively large eyes located posteriorly, preglabellar axial furrow and the glabella which is not so bulbous as usual in typical *Hystricurus*.

Occurrence:—Bunkoku formation at Shi 2.

Family Monkaspidae KOBAYASHI, 1935

(Maladidae HUPÉ, 1953)

The typical members of this family are characterized by the large or medium sized subquadrate glabella, two pairs of lateral furrows, clear-cut occiptal

ring without spine, medium sized eyes, distinct eye-ridge, thick convex marginal rim, diagonal anterior facial sutures, serrated margin of pygidium and smooth test or very fine granulation.

Monkaspis KOBAYASHI, 1934, (Text-fig. 1e-f) is represented by monotypic *Anomocare daulis* WALCOTT, 1905, which occurs in the late Middle Cambrian or Taitzuan-Kushanian passage in Shantung. Like some members of the Anomocaridae and Dikelocephalidae its cranidium has a semi-circular lobe on each side of the glabellar base. The eyes are, however, not so large as in the Anomocaridae and the brim is not so developed as in the Dikelocephalidae. Many small spines on each side of its pygidium are also quite distinctive from these families.
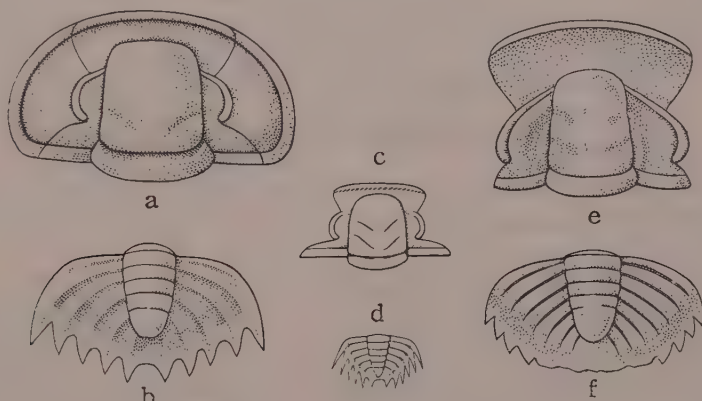
Figure 1.

a-b.   *Maladia americana* WALCOTT
c-d.   *Tostonia iole* (WALCOTT)
e-f.   *Monkaspis daulis* (WALCOTT)

In *Maladia* WALCOTT, 1942, (Text-figs. 1a-b) and *Tostonia* WALCOTT, 1924, (Text-figs. 1c-d) from the Upper Cambrian of western North America the glaballa becomes larger and the fixed cheek and frontal limb narrower. The pygidial spines in 5 or 6 pairs are more prominent than those of *Monkaspis* or *Yosimuraspis*.

In Tremadocian *Yosimuraspis* the glabella is similar to that of *Monkaspis* in relative size, but the lateral furrows are completely effaced and the marginal border is thickened and produced into a long genal spine. The facial sutures are intramarginal on the frontal border.

It is quite probable that the Eurekiinae HUPÉ, 1935, which include *Eurekia* WALCOTT, 1924, *Bayfieldia* CLARK, 1924, *Corbinia* WALCOTT, 1924, and probably *Apatokephaloides* RAYMOND, 1914, are different from the typical monkaspids in the smaller eyes, narrower frontal limb and fixed cheeks, less divergent or subparallel anterior sutures, greater relief of the shield and granulose test. It is, however, probable that they represent an Upper Cambrian branch of the Monkaspidae in North America.

Genus *Yosimuraspis* KOBAYASHI, new genus

Type-species:—*Yosimuraspis vulgaris* KOBAYASHI, new species.

Diagnosis:—Cephalon with conical smooth glabella, large eyes detached from it in posterior and broad free cheek with a long genal spine; facial suture half marginal on frontal border; pygidium small, relatively broad and provided with a few marginal spines.

Remarks:—Further informations are found in the description of the type-species. The genus is denominated in honour of the late Itiro YOSIMURA who has made a valuable contribution to the geology of the Yŏngwŏl (Neietsu) district.

Distribution:—Lowest Ordovician of South Korea.

Yosimuraspis vulgaris KOBAYASHI, new species

Plate XII, Figures 9-20, Text-figure 2.

Description:—Dorsal shield subelliptical and flattish; axial lobe narrower than pleural ones; test smooth.

Cephalon exclusive of stout spines large, semicircular and a little broader than twice its length; glabella truncate-conical, about two-thirds as long as cephalon, flat and unfurrowed; occipital ring somewhat broadened, short, though somewhat thickened mesially, and limited by a weak furrow in front; eyes large, half as long as glabella, starting from anterior of glabella, more or less protruded postero-laterally and terminates at a short distance from posterior of glabella; free cheek at eye nearly twice as broad as fixed cheek; preglabellar area bisected by a furrow into a nearly flat limb and moderately convex rim; genal spine protruded from marginal border as far as fifth or sixth thoracic segment. Anterior facial sutures diagonally divergent from eye-bands at a short distance from glabella,
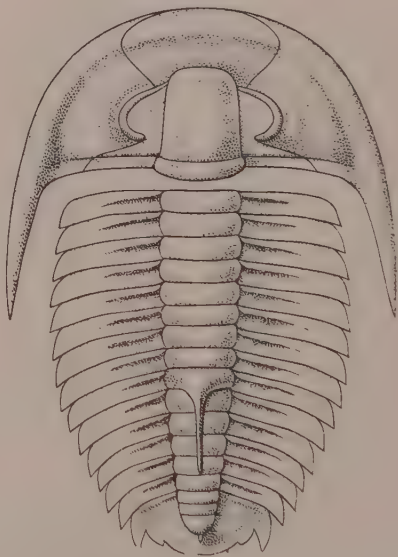
Figure 2.
Yosimuraspis vulgaris KOBAYASHI

but abruptly bent inward on border and running along its margin for some distance, join with each other and sagittal on doublure; their posterior branches gently inclined, but more abruptly before cutting posterior margin. Hypostoma subovate, but provided with a pair of small anterior wings, surrounded by a narrow rim and groove; main body swelling up and separated from a posterior lunate ridge by a pair of depressions.

Thorax composed of 14 or more segments, broadest on the 10th segment counted from posterior, where axial ring is slightly narrower than a fourth of thoracic breadth; 6th segment from posterior bears a sharply keeled, short axial spine; pleura truncated at lateral end and distinctly grooved in inner half where a pleural ridge is fairly prominent.

Pygidium small, relatively broad; axis short, conical, strongly convex and divided into two or three rings and a terminal lobe whence a tiny post-axial ridge issues; pleural lobe gently inclined and becomes subhorizontal near margin; first pleural furrow usually distinct, but others are not always discernible; first segment produced behind from border into a fairly long spine; second spine very short.

Test smooth.

Observation:—There are two hypostomata. One is broad and flat and the other long and inflated, but the difference depends probably on secondary deformation.

Occurrence:—Bunkoku formation at Locs. 234, 272, 277 and 289.

Yosimuraspis vulgaris subsp. *longulum* KOBAYASHI, new subsp.

Plate XII, Figures 7–8.

This is distinguished from the typical form primarily by the greater length of the glabella in comparison with the preglabella area. In the typical form the former inclusive of the occipital ring corresponds to twice the latter whereas in this subspecies the former exclusive of the ring is equal to twice the latter. In this subspecies a pair of pits are occasionally seen just behind the lateral ends of the glabellar front. Another pair are found less commonly close to the posterior ends of the eyes. Posterior lateral furrows appear to extend from the vicinities of the latter pits toward the median point of the neck ring. When depressed, three pairs of lateral furrows emerge on the surface where the anterior and middle ones are short and not so oblique as the posterior ones.

Occurrence:—Bunkoku formation at Locs. 234 and 92702.

Family Richardsonellidae RAYMOND, 1924

(Kainellidae ULRICH and RESSER, 1930)

The Remopleurinae were generally considered to be closely related to the Paradoxidae. SWINNERTON (1915) derived the Remopleuridae from the Mesonacidae. WARBURG (1925) noted the close resemblance of the Remopleuridae with *Apatokephalus* which was in turn considered by POULSEN (1927) an undoubted member of the Dikelocephalidae. POULSEN suggested the evolution from the Mesonacidae to the Remopleuridae through the Zacanthoidae and Dikelocephalidae. RICHTER (1933) placed the Remopleuridae in the Zacanthoididea of the Redlichiina.

In agreement with them I recognized in 1935 the Remopleuridae as a family

of the Mesonacida i.e. Redlichiida, to which, however, *Apatokephalus* and *Macropyge* were referred. At the same time I recognized the Kainellidae to be another family of the same order which was derived from the Zacanthoidae. Further I noted its alliance to the Richardsonellidae. Subsequently, in 1937, I distinguished the (1) *Apatokephaloides-Corbinia* group, (2) Kainellidae, (3) Macropygidae and (4) Remopleuridae and pointed out that the fourth family was introduced from the second through *Apatokephalus*. Next year HARRINGTON (1938) accepted the Kainellidae in the Mesonacida when he added *Pseudokainella* to it. In 1953 I reclassified the Kainellidae into the Kainellinae, Richardsonellinae, Apatokephalinae and Macropyginae and pointed out that the Remopleuridae developed from the Apatokephalinae probably through the forms like *Apatokephalus* and *Robergia* (Text-fig. 3c). Incidentally, *Corbinia* and *Apatokephaloides* are here located in the Eurekiinae of the Monkaspidae.
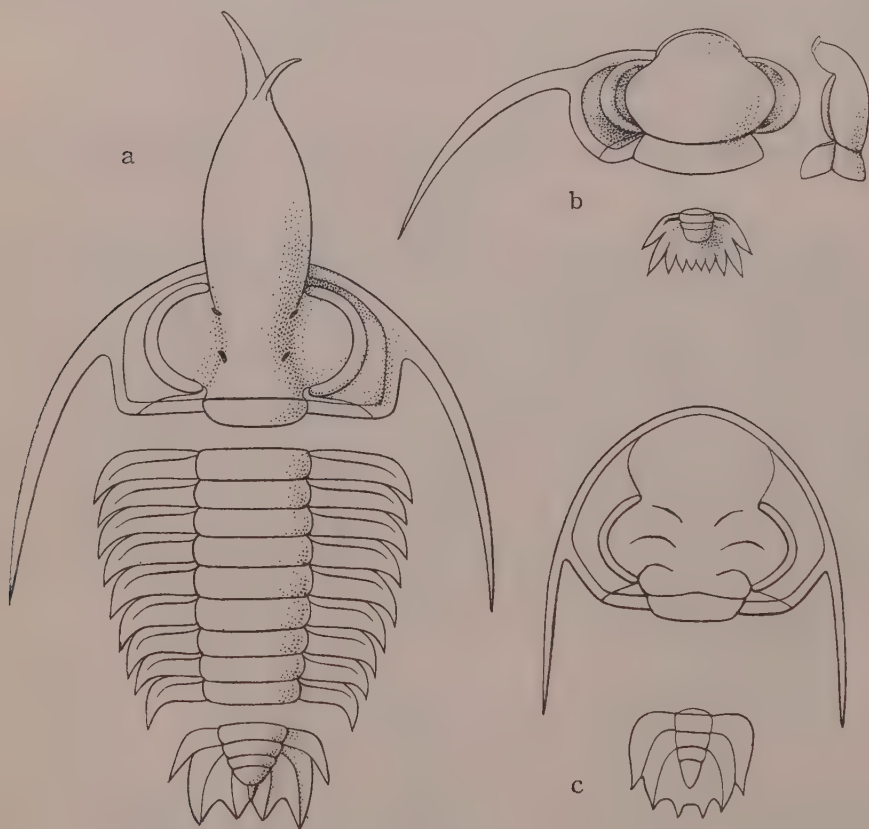
Figure 3.

a. *Teratorhynchus bicornis* (PORTLOCK)
b. *Remopleuridiella caudalimbata* ROSS
c. *Robergia microphthalmus* (LINNARSSON)

In 1951 HENNINGSMOEN removed the Richardsonellidae inclusive of the Kainellidae and the Remopleuridae inclusive of the Macropygidae from the Zacan-

thoididea and placed in the Dikelocephalacea which in turn he thinks a derivative from the Conocoryphacea. HUPÉ (1953) on the other hand, located the Remopleuridae and Richardsonellidae in the Olenoidae. In Treatise (1959) the Dikelocephalacea, Olenacea and Remopleuracea are accepted as three independent superfamilies, but all in the Ptychopatiina, where the Zacanthoididae are considered a family of the Corynexochida, following RASETTI (1951).
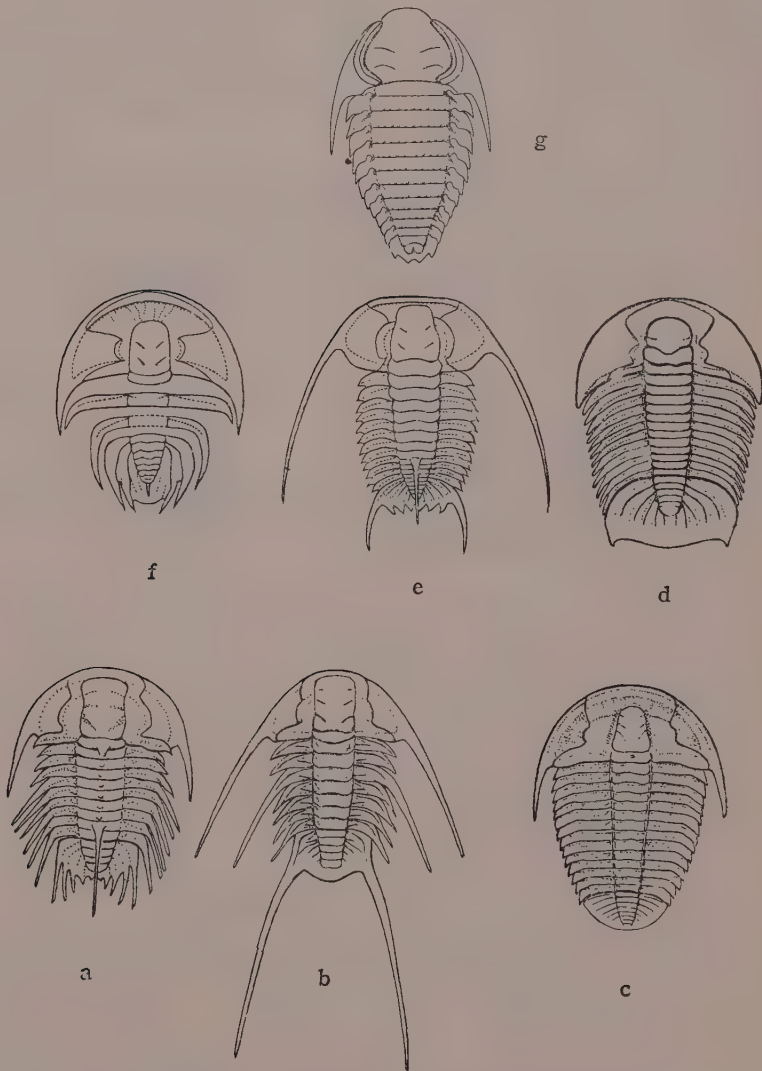
Figure 4.

a. *Zacanthoides spinosus* WALCOTT. (After RICHTER)
b. *Albertella helena* WALCOTT. (ditto.)
c. *Ptychoparia striata* (EMMERICH). (ditto.)
d. *Dikelocephalus oweni* ULRICH and RESSER. (ditto.)
e. *Pseudokainella keideli* HARRINGTON. (After HARRINGTON)
f. *Kainella billingsi* (WALCOTT). (After WALCOTT)
g. *Remopleurides colbi* PORTLOCK. (After WHITTINGTON)

The Richardsonellinae were originally proposed by RAYMOND as a sub-family of the Dikelocephalidae, when he instituted *Richardsonella*, 1924, on *Dikelocephalus megalops* BILLINGS. *Dikelocephalus oweni* BILLINGS was another species which RAYMOND assigned to this genus, but ULRICH (1930) erected *Levisella* out of it. In 1935 I tentatively added *Euloma* and *Loganellus* to the subfamily. Because these genera have the Ptychoparian nerve-like lines and wide subtriangular pygidia, I suggested the possibility of their derivation from the ptychoparian stock. Lately I combined *Euloma* with *Eulomella* in the Eulo-minae of the Ptychoparidae (1955). For the Longanellidae to which *Loganellus* and *Levisella* belong, RASETTI (1959) gave a statement, " Probably derived from Ptychopariids through *Wilbernia* or similar forms; also closely related to early Remopleuridae (*Richardsonella*)."

The ancestor is unknown of the Richardsonellidae (exclusive of Longanel-lids), but the family appears to be related to the Dikelocephalidae and Eureki-inae in many aspects. By this reason its derivation from the ptychoparian stock is probable and if so, the resemblance of *Kainella* or *Pseudokainella* re-spectively with *Zacanthoides* or *Albertella* becomes a remarkable example of homoeomorphy. (See Text-fig. 4).

The Richardsonellidae and Remopleuridae are different in the preglabellar area and anterior facial sutures. The thorax consists of 12 segments in *Apa-tokephalus* and *Pseudokainella*, but one segment is generally reduced in the Remopleuridae. *Remopleuridiella* (Text-fig. 3b) and *Teratorhynchus* 3a are highly specialized in the development of the glabella, diminution of the preglabellar area and others.

Macropyge has only 9 segments in thorax and is aberrant in the prolonga-tion of the spatulate pygidium. It differs from the Richardsonellidae and Re-mopleuridae further in the basal side-lobes on the glabella and the narrow preglabellar area. Ross (1951) noted the asaphoid aspect of the cephalon. It is proper to accept a small but distinct branch which issued in the Lower Ordovician period from the stem of the Richardsonellidae.

More Upper Cambrian members of the Richardsonellidae are expectable among the Asiatic trilobites which are however, not well known. *Mansuyia maladiformis* KOBAYASHI (1935, Text-fig. 5e) has the cranidium with a quadrate glabella, two pairs of pits on it, large eyes attached to the glabella and a broad preglabellar area, all of which are suggestive of the Kainellinae alliance. *Pseudokainella* (?) sp. (Text-fig. 5d) from loc. 263 is similar to *Conokephalina* on one side and *Pseudokainella* on the other, but the eyes are detouched from the glabella.

The following three genera from the Upper Cambrian of the Salair moun-tains, Siberia, are attributed by the authors (1955) to the Remopleuridae, s. l.

1. *Apatokephalina bruta* SIVOV (Text-fig. 5c), monotypic of the genus, is said intermediate between *Richardsonella* and *Apatokephaloides*. In my opinion it constitutes a group probably of the Richardsonellidae with *Princetonella* LOCHMAN, 1953, which is totally different from the Komaspidae in the semicircular eyes attached to the glabella at the posterior extremities.

2. *Artokephalus* Sivov and Jegorova which is founded on *A. minimus* Sivov (Text-fig. 5b) is also considered an ally to *Apatokephaloides* and *Richardsonella*. These North American genera, however, can easily be distinguished from this as well as *Apatokephalina* by the greater preglabellar area which consists of a narrow rim and a limb of moderate size.

3. *Portentosus brevis* Jegorova (Text-fig. 5a) is represented by relatively flat cranidia having a conical glabella with three pairs of weak lateral furrows, large semicircular eye bands and a narrow frontal border separated from the glabella by a groove.   Except the conical outline of the glabella it appears allied to *Hukasawaia*.

Here is described an Ordovician genus, *Aotiaspis*.
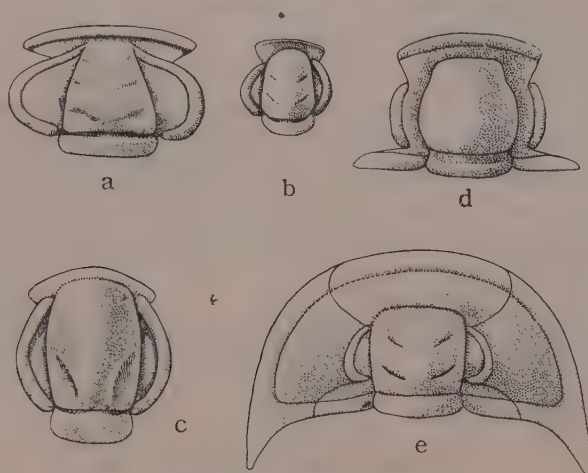
Figure 5.

a. *Portentosus brevis* Jegorova
b. *Artokephalus minimus* Sivov
c. *Apatokephalina bruta* Sivov
d. *Pseudokainella* (?) sp. indt.
e. " *Pseudokainella* " *maladiformis* (Kobayashi)

Subfamily Richardsonellinae Raymond, 1924

Genus *Richardsonella* Raymond, 1924

Richardsonella flabellifera (Hall and Whitfield), 1877

Text-figure 8e

1877. *Dikellocephalus flabellifer* Hall and Whitfield, *U. S. Geol. Expl. 40th Par., Vol. 4,* p. 227, pl. 2, figs. 29–30.
1914. *Apatokephalus flabellifer* Walcott, *Smiths. Misc. Coll. Vol. 57, No. 3,* p. 350.
1938. *Parabriscoia flabellifera* Resser, *Smiths. Misc. Coll. Vol. 97, No. 10,* p. 38.
1953. *Parabriscoia* (?) *flabellifer* Kobayashi, *Japan. Jour. Geol. Geogr. Vol. 23,* p. 58.

As suggested by Walcott, certainly the pygidium resembles that of *Apatokephalus* in the outline and narrow axis. But in *flabellifer* each pleural rib terminates at a sinuation and an interpleural depression extends in form of a

short flat spine. Beside three pairs of such spines the authors illustrated a posterior obtuse spine on which the last pleural ribs are fused to form a post-axial ridge.

In the plaster casts and their photographs of the holo- and paratype, however, the margin appears to be somewhat sinuated, instead of projected and more or less elevated toward the post-axial ridge. The aspect suggests the fusion of the fourth pair of pleurae and of the pleural ribs which the latter is thought to become the post-axial ridge. Furthermore the first pleura is longer than its original illustration.

As I have cast a question already (1953), the pygidium is evidently distinct from *Parabriscoia* (or *Elkia*) to which Resser (1938) referred. In my opinion it agrees best with *Richardsonella* (or *Protapatokephalus*). The associated pygidia of *R. megalops* (Billings), 1860, and *R. unisulcata* Rasetti, 1944, have the post-axial sinus and three spines on each side. In them, however, the axial lobe is relatively broad and consists of three rings and a terminal lobe, while the axial lobe of this species is more slender and composed of 5 rings and a terminal lobe. *Protapatokephalus arctostriatus* Raymond, 1937, and *P. spiculatus* Raymond, 1937, have more spines on their pygidia and 5 or 6 pairs are countable in the respective species. Therefore this species can readily be distinguished from these allied ones.

Distribution:—Dark crystalline limestone (Upper Cambrian Secret Canyon) of the Potsdam group on the west side of the Pogonip Mountains, White Pine district and in Eureka district, Nevada.

Genus *Hukasawaia* Kobayashi, 1953

Type-species:—*Hukasawaia cylindrica* Kobayashi, 1953.

Remarks:—In the long narrow glabella to which a large semicircular eye-band is attached on each side this genus resembles *Macroculites*, but in that genus the glabella tapers forward and the concave proglabellar brim is present, but absent in this genus.

Distribution:—Lower Ordovician ; Korea.

Hukasawaia cylindrica Kobayashi, 1953

Text-figure 6g.

1953. *Hukasawaia cylindrica* Kobayashi, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 50, pl. 3, fig. 15.

Occurrence:—Bunkoku formation; Loc. 252.

Subfamily Kainellinae Ulrich and Resser, 1930

Genus *Kainella* Walcott, 1924

Since the find of this genus in the collection from Prerie Catamarca, Argentina (Kobayashi 1,935) its flourishment in the Andean geosyncline was thoroughly

manifested by HARRINGTON and LEANZA (1957). It is distributed further in South Korea, Hopei (?), Szachuan and Yunnan-Tonkin border (1953). According to SHENG (1956) *Kainella lohanpoensis* is accompanied in Szechuan by *Andesaspis sinensis* which belongs probably to *Parabolinopsis*.
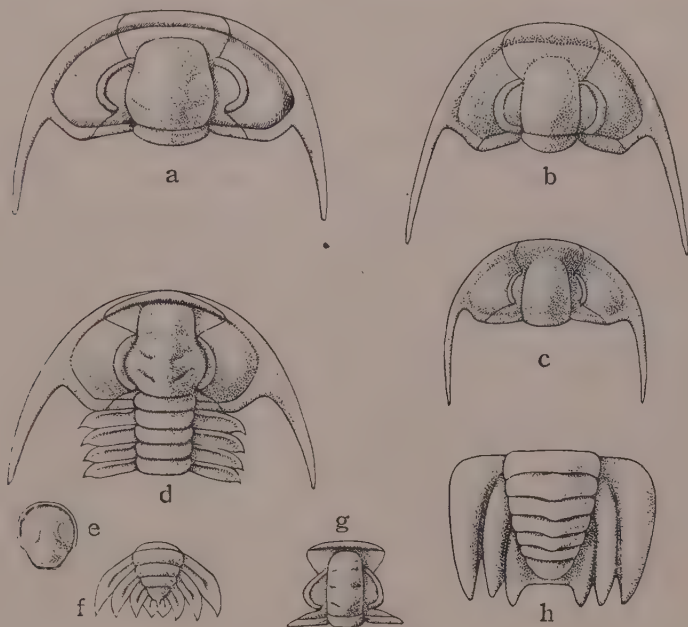
Figure 6.

a. *Pseudokainella iwayai* KOBAYASHI
b. *Aotiaspis oblonga* KOBAYASHI
c. *Aotiaspis lohanpoensis* (SHENG)
d—f. *Apatokephalus hyotan* KOBAYASHI
g. *Hukasawaia cylindrica* KOBAYASHI
h. *Kainella euryrachis* KOBAYASHI

Kainella euryrachis KOBAYASHI, 1953

Text-figure 6h.

1953. *Kainella euryrachis* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 45, pl. 3, fig. 9.

Occurrence:—Tomkolian argillaceous limestone at Sei 14.

Genus *Pseudokainella* HARRINGTON, 1938

Pseudokainella iwayai KOBAYASHI, 1953

Text-figure 6a.

1953. *Pseudokainella iwayai* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 46, pl. 3, figs. 2-14.

Occurrence:—Limestone lens in the Doten quartzite at Yon'pyongni near

Uiimgil, Sangdong-myŏn, Yŏngwŏl, Kangwŏn-do (江原道寧越郡義林古遠坪里), Iwaya Collection.

Pseudokainella a sp.

1953. *Pseudokainella* a sp. Kobayashi, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 4, pl. 3, fig. 16.

Occurrence:—Bunkoku formation, Loc. 221.

Pseudokainella (?) sp. nov.

Plate XII, Figure 1, Text-figure 5d.

An imperfect but interesting cranidium with a large glabella which is as long as wide, most expanded at the mid-length, narrower in anterior than in posterior, surrounded by deep furrows, distinctly elevated, but not strongly inflated; lateral furrows absent; occipital furrow deeper; occipital ring narrow and moderately arcuate; eye-bands two-thirds as long as glabella, attached to it at the anterior end, but detached from it by a narrow space at the posterior end; intra-ocular part of fixed cheek narrow and long; postocular limb apparently short and broad; preocular limb small and triangular; frontal limb absent; frontal border as thick as frontal groove and somewhat narrowing laterally.

This looks like *Pseudokainella* (?) *macarenae* Harrington and Kay (1951), especially the one in fig. 21, in the outline of the glabella, but a well developed frontal limb is present in their form from East Columbia. In the presence of the intraocular cheek it is distinct from *Apatokephalus* and agrees with *Hukasawaia* and *Menoparia*. In the shape of the glabella it is more allied to *Menoparia* than *Hukasawaia*, but the glabellar furrows are undeveloped in this as in *Hukasawaia*. The eye-band is not semi-circular as in most kainellids, but elongated as in *Tramoria*. Judging from the combination of these biocharacters this represents an undescribed genus, although the specimen before hand is too poorly preserved to propose a new name.

Occurrence:—Gakoku formation at Loc. 263.

Genus *Aotiaspis* Kobayashi, new genus

Type-species:—*Aotiaspis oblonga* Kobayashi, new species.

The generic name is dedicated to the late Kiyohiko Aoti who made a valuable contribution to the geology of the Mun'gyŏng District. It includes kainelloids having the cephalon more similar to *Kainella* than *Pseudokainella* in the presence of the frontal limb of moderate size, but it is not so laterally expanded as in *Kainella*, because the anterior sutures are diagonal, instead of transversal in *Kainella*. The glabella is evidently more rounded in this genus. The complete effacement of lateral furrows and the absence of pits on the frontal groove are two important distinctions from *Kainella*, *Pseudokainella* and other allied genera. In the broad outline and serrated margin the associated pygidium best agrees with that of *Apatokephalus*.

Beside the type species the genus is represented in Korea by *Aotiaspis ovalis*, nov. and *Pseudokainella* (?) b sp. (KOBAYASHI, 1953). *Kainella lohanpoensis* SHENG from Szechuan-Kweichow border may be an additional member of the genus.

Distribution:—Lower Ordovician; Eastern Asia.

Aotiaspis oblonga KOBAYASHI, new species

Plate XIV, Figures 7–13, Text-figure 6b.

Description:—Cephalon not much inflated but glabella is fairly convex, rising above cheeks three-fourths as long as cephalon, subelliptical, parallel-sided in middle part where its breadth corresponds to a half of cephalic length, distinctly elevated above cheeks; no lateral furrows; occipital furrow deep; occipital ring short and narrows laterally; eye-band semicircular, as long as a half of cephalon exclusive of neck ring and directly attached with glabella; frontal limb and border nearly equal in length, the border being only a little convex and elevated above the limb; marginal groove shallow and lacks a row of pits; free cheek of moderate size; its postero-lateral margin straight, forming an obtuse intergenal angle with posterior margin of cranidium; ocular platform a little more inflated than lateral border; the two parts separated by marginal groove; facial suture diagonal anterior to eye and intramarginal for a short distance on frontal border; suture posterior to eye transversal and abruptly turning toward intergenal angle.

Pygidium twice broader than long, gently convex; axial lobe a little narrower than a third of pygidium, moderately convex, elevated above side-lobes and quinquipartate by four ring-furrows; pleural and interpleural furrows present; pleura produced into a short spine at the end.

Occurrence:—Tomkolian; Shi 2.

Aotiaspis ovalis KOBAYASHI, new species.

Plate XIV, Figure 14.

This species differs primarily for the preceding in the outline of the glabella which tapers gradually forward. It is subtruncated in front in a cranidium, but more rounded in a large illustrated cranidium. In these cranidia the preglabellar area is remarkably bent down laterally. In the large one the marginal furrow is shallow and so obliterated that the frontal limb appears to merge into the frontal border. The difference of convexity between the two parts is also reduced.

Occurrence:—Same as the preceding.

Aotiaspis lohanpoensis (SHENG), 1958

Text-figure 6c.

1958. *Kainella lohanpoensis* SHENG, *Acta Pal. Sinica, Vol. 6, No. 2*, p. 187, pl. 1, figs. 2a–j.

This species fits in *Aotiaspis* nicely in the relatively large oblong glabella, obsolete lateral furrows, short preglabellar area and the small angle between the divergent anterior facial sutures. Compared to the Korean forms of the genus, the eyes are smaller and the frontal and occipital furrows more effaced in this species.

Occurrence:—Basal Ordovician. Lohanp'o formation at Omeishan, Szechuan; lower Tungtzu formation at Tungtzu, Kweichow, China.

Aotiaspis sp. indt.

1953. *Pseudokainella* (?) b sp. KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 47, pl. 3, figs. 10–11.

This form agrees better with *Aotiaspis oblonga* than with any other kainelloid that I know, but evidently distinct from that species in the more quadrate outline and much stronger convexity of the glabella and rudimentary lateral furrows which are perceptible only under cross light and shorter genal spine on the associated free cheek.

Occurrence:—Bunkoku formation at Loc. 221; Tomkol shale at Sei 14.

Genus *Apatokephalus* BRÖGGER, 1897

Apatokephalus hyotan KOBAYASHI, 1953

Text-figures 6d–f.

1953. *Apatokephalus hyotan* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 52, pl. 3, figs. 17–23.

Occurrence:—Bunkoku formation; common at Loc. 238, but occurring also at Locs. 248 and 249.

Suborder Dikelocephalidina KOBAYASHI, 1936

Family Dikelocephalidae MILLER, 1889

While SWINNERTON placed the Dikelocephalidae and Asaphidae in his Ptychoparina, POULSEN and RICHTER agree in that the two families in addition to the Remopleuridae are derivatives from the Zacanthoididae. Because the ancester of the Dikelocephalidae was in question, I erected Dikelocephalida in 1935, as a separate order. In the next year, however, I pointed out that the Dikelocephalidae were evolved from *Alokistocare* through *Paracoosia*. Broadly speaking, it means that the family was derived from the Ptychoparid stock through the Anomocaridae. Lately HENNINGSMOEN accepted the Anomocaridae as a member of the Conocoryphacea, i. e. the ptychoparid group. HUPÉ on the other hand, made the Anomocarinae a subfamily of the Dikelocephalidae. In other words the two evolutional segments figured by the two authors are linked at the Anomocaridae in the evolutional line which I suggested in 1936.

Subfamily Dikelocephalinae MILLER, 1889

This subfamily is represented in Eastern Asia by *Briscoia*, *Dikelocephalites* and *Coreanocephalus*. The first of them is a cosmopolitan genus distributing from Britain to Persia through North America and Eastern Asia. *Saukia* (*Briscoia*?) *vagans* REED, 1934, from Kashmir is however, evidently not a *Briscoia*. Previously I have noted that *Coreanocephalus*, *Dikelocephalites* and *Parabriscoia* are endemic off-shoots from the main stem.

As noted by SUN (1935), the associated free cheek of *Dikelocephalites flabelliformis* (Text-fig. 7b) is broad and triangular in outline with an obtuse genal angle. The genal spine is present in *Coreanocephalus kogenense*. (Text-fig. 7a).
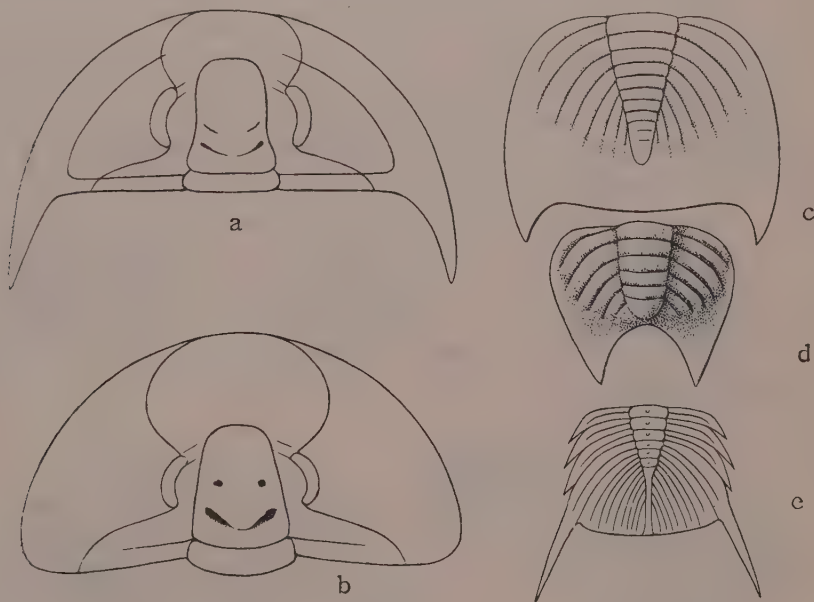
Figure 7.

  a. *Coreanocephalus kogenense* KOBAYASHI
  b. *Dikelocephalites flabelliformis* SUN
  c. *Dainellicauda elegantulus* (GORTANI)
  d. *Temnura granulosa* RESSER and ENDO
  e. *Girvanopyge problematica* (REED)

The pygidia of *Parabriscoia dolichorachis* are said by LOCHMAN (1956) to occur in the lower Pogonip, in Nevada always in association with the cranidia of *Elkia nasuta*. By this reason *Parabriscoia* (Text-fig. 8f) founded on the pygidium is now combined with cephalon of *Elkia*. By some reason, however, MERTIE's collection from Alaska contained many pygidia of the genus, but no *Elkia* cephalon, although detached cephala as well as pygidia of *Briscoia* were as abundant as the pygidia of *Parabriscoia*.

Here a new genus, *Hederacauda*, is added to them.

Genus *Hederacauda* KOBAYASHI, new genus

Type-species :—Dikellocephalus multicinctus HALL and WHITFIELD, 1877

*Diagnosis :—*Dikelocephalid with unfurrowed conical glabella, rounded in front, medium sized eyes, oblique eye-ridges; fairly broad depressed brim, genal spine of moderate length and intramarginal anterior sutures; pygidium subtriangular, multisegmented, provided with slender long axis and depressed border having a few serrations.

*Distribution :—*Upper Cambrian; eastern North America.

Hederacauda multicincta (HALL and WHITFIELD), 1877

Text-figures 8c–d.

1877. *Dikellocephalus multicinctus* HALL and WHITFIELD, *U.S. Geol. Expl. 40th Par. Vol. 4*, p. 226, pl. 2, fig. 36.
1914. *Apatokephalus multicinctus* WALCOTT, *Smiths. Misc. Coll. Vol. 57, No. 3*, p. 352.
1938. *Pterocephalia multicincta* RESSER, *Smiths. Misc. Coll. Vol. 97, No. 10*, p. 39.
1953. *Pterocephalia* (?) *multicincta* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 23*, p. 58.
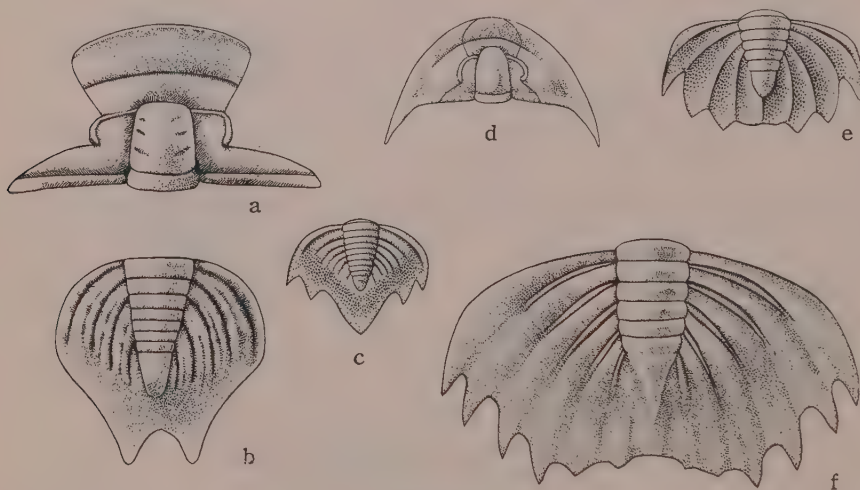
Figure 8.

a–b.   *Dikelocephalopsis amsassensis* POLETAYEVA
c–d.   *Hederacauda multicincta* (HALL and WHITFIELD)
e.   *Richardsonella flabellifera* (HALL and WHITFIELD)
f.   *Elkia elegans* (KOBAYASHI)

This was once referred to *Apatokephalus* by WALCOTT and to *Pterocephalia* by RESSER, but I questioned this reference. Its subtriangular and multisegmented pygidium with the slender axis and only 5 spines on the margin exclude it from either the above two genera or any other known genus. Judging from the postero-lateral margin, the restoration by the authors may be accepted for the large rear spine and the second lateral one, but the spines are strongly destroyed on the holotype.

The associated cranidium has a narrow glabella without lateral furrows, but with an axial carination and occipital furrow; eye-band of moderate size connected with glabella by distinct oblique eye-ridge; frontal brim twice longer than frontal limb, depressed and concave. Free cheek fairly broad; its depressed border protruded into a genal spine. Two branches of facial suture diagonally divergent from eye and intramarginal on frontal border.

The cephalon can easily be distinguished from that of *Pterocephalia* in the relatively long glabella, obsolete lateral furrows, much shorter brim and the course of the facial suture. The pygidium is of course different in outline. It is distinct from the pygidium of *Parabriscoia* or *Elkia* in the longer and more triangular outline and the mode of marginal serration.

Distribution:—Limestone (Upper °Cambrian, Secret Caynon) of Potsdam group; Pogonip Mountain, White Pine district, Nevada.

Subfamily Dikelokephalininae KOBAYASHI, 1936

It looks to me improbable that the dikelokephalinids are phylogentically closer to the asaphids than the dikelocephalids as considered by LOCHMAN (1959), because the first and third groups have many biocharacters common between them, while the second is distinct from these two groups. Because the first flourished in Upper Cambrian and the third in Lower Ordovician, the Dikelokephalininae were established with the thought that the subfamily was derived from the Dikelocephalinae. As discussed later, there is no Upper Cambrian asaphid which is so closely related to the Dikelokephalininae that it can be considered ancestral.

Like in the Dikelocephalinae, the glabella of the Dikelokephalininae is generally conical and rounded in front, but the posterior furrows are rare to be connected on the axis as in the former. Lateral furrows are somewhat pitted in the latter and entirely effaced in *Dikelokephalina ulrichi* Růžička, 1926. The basal side-lobes are often seen in the latter. Eyes are medium in size and connected with the glabella by oblique eye-ridges. Facial sutures are semicircular in front of the eyes and then run along the frontal margin; median suture crosses the doublure. The hypostoma of *D. ulrichi* is more rounded than those of *Dikelocephalus* and has a shallow posterior sinuation.

The thorax has 12 segments in *Asaphopsis welleri brevica* (SHENG), 1934 and 13 segments in *Hungioides graphicus* RICHTER, 1954. The pygidium is provided with a pair of spines in most genera and with two pairs of them in *Hungioides*. Interpleural furrows are generally absent, but present in *Dikelocephalopsis*.

Beside *Dikelokephalina* BRÖGGER, 1896, this subfamily includes *Asaphopsis* MANSUY, 1920, *Hungioides* KOBAYASHI, 1936, *Dactylocephalus* HSÜ, 1948, *Asaphopsoides* HUPÉ, 1955, and probably *Leimitzia* SDUZY, 1955, *Dikelocephalopsis* POLETAYEVA, 1955, and *Temnura* RESSER and ENDO, 1937.

Leimitzia was founded by the author on *Conocephalites bavaricus* BARRANDE as a subgenus of *Pterocephalina* in the Paracoosiinae. Its pygidium is sinuated at the hind, but bears no spine. The basal side-lobes are distinctly marked

on the cranidium. *Temnura* (Text-fig. 7d) is represented by the pygidium resembling *Uncaspis* on one side and *Dactylocephalus* on the other. Whether it is a member of this subfamily or whether it is a relic of the Crepicephalidae cannot be solved without its cephalon.

Dikelocephalopsis POLETAYEVA (Text-fig. 8a–b) was originally proposed as a genus of the Dikelocephalidae. It is referred to the Dikelokephalininae in Treatise (1959), noting its resemblance with *Leimitzia*. The pygidium of *Dikelocephalopsis* is certainly allied to those of *Dikelokephalina* and *Dactylocephalus*, but in the thick frontal border of the cranidium it agrees better with *Leimitzia* than these two allies. The relatively small eyes connected with the glabella by long eye ridges and the large laterally prolonged posterolateral limb of the fixed cheek are quite strange for the Dikelokephalininae. In the general outline of the cranidium it resembles *Wentsuia* and *Tingocephalus* for the last of which HUPÉ proposed Tingocephalinae. It is a question if these three genera constitute a separate group.

Here *Dainellicauda* is proposed for *Asaphus elegantulus* and *Girvanopyge* for *Lichapyge* (?) *problematicum*. It is beyond doubt that the last species represents a new genus, but its belonging to this family is not highly probable.

Distribution :—Lower and Middle (?) Ordovician ; Eurasia and Tasmania.

Genus *Dikelokephalina* BRÖGGER, 1896

Dikelokephalina parva KOBAYASHI, new species

Plate XIII, Figures 27–30.

Description :—Glabella convex, remarkably elevated above cheeks, two-thirds as long as cranidium, gently tapering forward, and rounded in front, its breadth at the neck corresponding to a half length of cranidium ; postero-lateral and occipital furrows remarkably oblique, the latter narrow, deep and running across the glabella, while the former is discrepant on axis, broadened laterally and confluent with dorsal furrows ; long lobe of glabella anterior to this furrow subcylindrical ; posterior lobe very narrow, and interrupting the dorsal furrow, it extends into cheeks ; occipital lobe narrow and bent backward ; median tubercle indiscernible on the neck ; eyes medium in size, located a little posterior to the middle of glabella and connected with glabella by a blunt oblique eye-ridge ; frontal brim well developed ; facial suture semi-circular in front of eyes.

Observation :—The holotype measures 1.3 mm. in length (fig. 27). Another cranidium (fig. 28), also very small, is not well preserved. There are three pygidia, the largest of which is 7.5 mm. broad.

Comparison :—The large pygidium of *Dikelokephalina* from loc. 249 is a little longer, its axial lobe more cylindrical, and posterior spines are narrower and longer, if compared with the pygidium of *D. asiatica*. Its lateral margin appears more or less wavy. The above described cephalon is quite distinct from *D. asiatica*, *D. kanaegata* or any other species of *Dikelokephalina*.

Occurrence :—Bunkoku formation at Locs. 248 and 249.

Dikelokephalina conica Kobayashi, new species

Plate XIII, Figure 31.

Compared to the preceding, the glabella is more conical and more strongly convex and the palpebral lobe larger. The posterior furrows tend to be pronounced pits, while the dorsal furrow is weakened. This has a median tubercle on the V-shaped line drawn by the posterior furrows. The anterior margin of the glabella is nearly straight and the frontal brim concave whereas it is nearly flat in the preceding.

The holotype cranidium is 3 mm. long. An imperfect cheek fitting this cranidium is found on the same slab. It shows the wide doublure suggesting for the facial suture to be marginal and meeting its fellow in front of the cephalon to form a median suture on the doublure.

Occurrence :—Bunkoku formation at Loc. 248.

Genus *Asaphopsis* Mansuy, 1920

Asaphopsis nakamurai Kobayashi, 1936

1936. *Asaphopsis nakamurai* Kobayashi, *Japan. Jour. Geol. Geogr. Vol. 13*, p. 175, pl. 20, figs. 18–20, pl. 21, fig. 12.

Occurrence :—Tomkol shale at Doten. Coll. of Geol. Inst. Kyoto Univ.

Asaphopsis cfr. *nakamurai* Kobayashi, 1936

1936. *Asaphopsis* cfr. *nakamurai* Kobayashi, *Ibid. Vol. 13*, p. 176, pl. 21, fig. 14.

Occurrence :—Same at the preceding. Coll. of Geol. Inst. Kyoto Univ.

Genus *Dainellicauda* Kobayashi, new genus

Type-species :—*Asaphus elegantulus* Gortani, 1934 (Text-fig. 7c)

Diagnosis :—Dikelocephalid-pygidium whose antero-lateral margin is regularly rounded; lateral border terminating behind at a short spine; axial lobe narrow, longiconic and multisegmented; interpleural furrows absent.

Remarks :—As noted already (1936), this agrees better with *Dikelocephalus* rather than *Asaphopsis* in outline, but evidently too long for *Dikelocephalus*. The spine issues from the anterior in this, instead of the middle segment in *Asaphopsis*. The type pygidium was collected by Prof. Giotto. Dainelli at Chisil, Carakorum in association with other trilobites, cephalopods and so forth which as a whole indicate Llandeilian, or Llanvirnian for the age of the fauna. In other words, it is younger than *Dikelocephalus* or even *Asaphopsis*.

Distribution :—Middle Ordovician; Himalayan geosyncline.

Genus *Girvanopyge* KOBAYASHI, new genus

Type species:—Lichapyge (?) *problematica* REED, 1906, i. e. *Dionide* (?) sp. by NICHOLSON and ETHERIDGE, 1880. (Text-fig. 7e)

Similar to *Dainellicauda*, but the anterior margin is strongly arcuate, axial lobe short, conical and produced into a long slender post-axial ridge, pleural and interpleural furrows extending far toward the posterior margin, and a long spine issuing from the first pleural segment.

As pointed out elsewhere (1936), it is quite distinct from either *Dionide* or *Lichapyge* to which it has been compared. It may be more similar to *Dainellicauda* than those two genera, insofar as the pygidium is concerned. It is, however, distinct from the Dikelokephalininae in the long pleural and interpleural furrows and also the short axis with a long post-axial ridge. There is no question about its being a new genus, but its reference to this subfamily or family is very tentative.

*Distribution :—*This is the latest of the family, if it be really a dikelocephalid, because the type pygidium occurs in the Whitehouse group (Middle Bala) of Girvan, Scotland.

Genus *Hungioides* KOBAYASHI, 1936

This is different from all of the preceding genera in the possession of two pairs of spines on the pygidium. Beside *Dicellocephalina bohemica* PERNER in NOVAK and PERNER, 1918, which is the type-species the genus comprises the followings ;

    Hungioides novaki KOBAYASHI, 1936.

    Hungioides graphicus RICHTERS, 1954.

    Hungioides bohemicus arouquensis THADEU, 1955.

Now *Hungioides* is not restricted to the dγ1 stage of Bohemia, but occurs in the Griffelschiefer of Thüringia and in the Llandeilian (?) slate in the south of Douro, Portugal.

Family Birmanitidae KOBAYASHI, new family

This family typified by *Birmanites* is different from the typical Dikelocephalidae primarily in the absence of spines on the pygidium. It looks like an asaphoid and the thorax is composed of 8 segments; the eyes are too large and such a large brim as seen in *Birmanites* is never found in the Asaphidae. The genus was proposed by SHENG (1934) with *Birmanites birmanicus* (REED) from the Tremadocian of Chekiang, Central China. Its cephalon is different from those of dikelocephalids in the urceolate glabella to which large semicircular eyes are attached.

As noted already (1950), *Ogyginus* aff. *cordensis* by KOBAYASHI (1934), from the Tomkolian of South Korea probably represents an undescribed species of *Birmanites*.

Caradocian *Birmanites hupeiensis* Yɪ, 1957, (Text-fig. 9c) from the Yangtze gorge has a pair of prolonged triangular basal lobes on the glabella which would serve for distinction from *Birmanites* s. str. Because this morphic differencecorresponds to the time displacement from Lower Ordovician *Birmanites*,
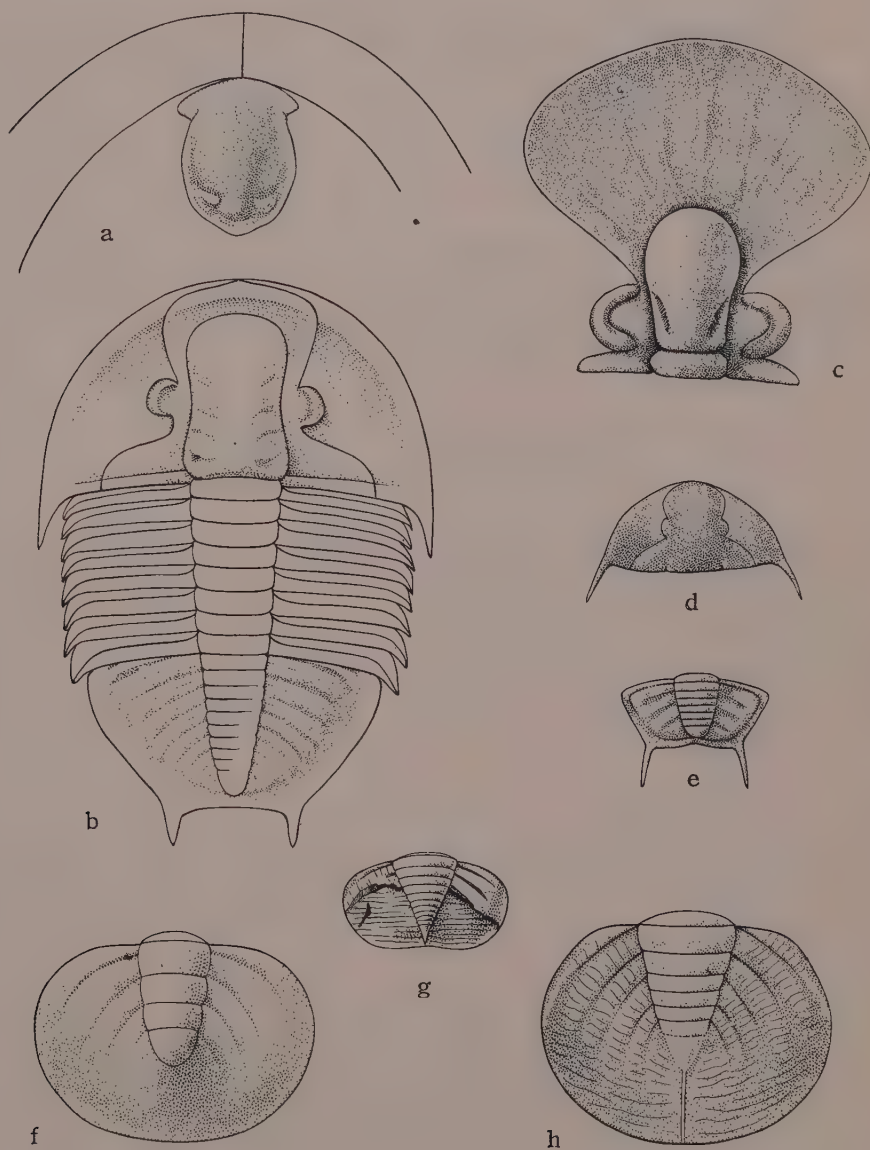
Figure 9.

a, b.   *Asaphelina barroisi* Munier-Chalmas et Bergeron
c.   *Birmanites (Birmanitella) hupeiensis* Yɪ
d, e.   *Tungtzuella kweichowensis* Sheng
f.   *Hagiorites omeishanensis* Kobayashi
g.   *Hagiorites (?) sp.*
h.   *Tropidopyge bröggeri* (Moberg and Segereerg)

Birmanitella is proposed for this Caradocian species.

Birmanites, s. l. of the Birmanitidae may not be endemic to Eastern or Southeastern Asia, seeing that *Ogygites* cfr. *birmanicus* is reported to occur in the Middle Ordovician Ishimsk formation in the northeastern part of Kazakstan (BELIAEVSKY et. al. 1958).

Tripidopyge HARRINGTON and KAY, 1951 (Text-fig. 9h) and *Hagiorites* KOBA-YASHI, 1951 (Text-fig. 9f) were both founded on aspinose pygidia of dikelo-cephaloid-aspect. The former was first proposed as a genus of the Dikelo-cephalidae, but later transfered by HARAINGTON and LEANZA (1957) into their Hypermecaspidae. The latter genus is different from the former in the sub-cylindrical axial lobe well round at the rear whence no post-axial ridge issues.

Hagiorites (?) sp. by KOBAYASHI, 1951, (Text-fig. 9g) having a broad elliptical pygidium, short conical axis and wide doublure belongs most probably to an unnamed genus, but little is known to settle its taxonomy.

Distribution :—Ordovician ; Eastern and (?) Central Asia.

Suborder Asaphina SALTER, 1864

Family Taihungshaniidae SUN, 1931

Taihungshania, Omeipsis, Asaphelina and *Tungtzuella* are generally referred to this family. Putting aside *Omeipsis*, the remaining three genera agree with one another in the possession of one pair of spines on the pygidium, but they are quite different in many other aspects. *Asaphelina* (Text-fig. 9a–b) is more allied to the Niobinae or Ogygiocardinae than *Taihungshania*, while *Tungtzuella* (Text-fig. 9d–e) resembles certain genera of the Isotelinae, *Isoteloides* for ex-ample. I think it quite probable that these two genera are independent off-shoots from different branches of the Asaphidae. The hypostoma associated with *Tungtzuella yunnanensis* is subtriangular, but well rounded in posterior and alate on the two sides of the anterior margin. It is quite different from the hypostomata of the Asaphidae and Taihungshaniidae. Therefore it is also probable for *Tungtzuella* to be derived from the Tsinanidae or some other Upper Cambrian branch.

The glabella is narrowing backward in *Taihungshania* and forward in *Omeipsis*. The pygidium of the former or latter genus has one or two pairs of spines respectively. The two genera, however, agree in the relatively long glabella and small eyes located anteriorly and close to the glabella. While *Taihungshania* is widely distributed from Arenigian to early Llandeilian, or possibly appears already in the late Tremadocian, *Omeipsis huangi* is monotypic of the genus and its occurrence is restricted to the top (lower Llandeilian) of the Tachengssu formation of Szechuan.

Genus *Taikungshania* SUN, 1931

Taihungshania was greatly amplified in China by SHENG (1958) and com-

prises 5 species and 3 varieties. It is interesting to see among them that there are two morphological series.

1. *Shui* series having semi-parabolic and multisegmented pygidia.

    Taihungshania miqueli (BERGERON) by SHENG.

    Taihungshania shui SUN.

    Taihungshania multisegmenta SHENG.

2. *Brevica* series having semi-circular and paucisegmented pygidia.

    Taihungshania brevica SHENG.

    T. brevica var. *tachengssuensis* SHENG.

    T. brevica var. *orientalis* SHENG.

    Taihungshania omeishanensis SHENG.

    T. omeishanensis var. *liui* SHENG.

    T. brevica is long-ranged whereas *T. omeishanensis* is a short-ranged terminal species introduced by the hypertrophy of the axial lobe. Likewise, *T. multisegmenta* having more than 21 rings on the axis of the pygidium is the terminal species of the *shui* series in which the axial lobe is generally divided into 14 to 16 rings.

    In looking through these Chinese forms it can hardly be overlooked that the genal angle issues from the lateral side and the intergenal angle is distinct in *Taihungshania* s. str. If special weight is laid on these characteristics, *Miquelina miqueli* (BERGERON) and its varieties must be segregated from *Taihungshania*, and *Miquelina* THORAL, 1935, revived for the Mediterranian forms. *Taihugshania hectori* (REED) from New Zealand (KOBAYASHI, 1940) is closer to *Miquelina* than *Taihungshania* s. str. in the lack of the intergenal angle, but evidently distinct from them in the development of the eyes at the relatively posterior position, although the specimens are so crudely deformed to restore the original form correctly.

Family Asaphidae BURMEISTER, 1843

    There are five asaphoid genera in the Upper Cambrian. *Charchaqia* is one of them which is now known to have been widely distributed from East Tienshan to Australia through Kweichow, South China, in association with *Hedinaspis* or *Eugonocare*. The genus was founded by TROEDSSON on *Charchaqia norini* (Text-fig. 10h) and placed in the Ogyginae of the Asaphidae. It is however, quite distinct from other genera of the Asaphidae in the narrow unfurrowed cylindrical glabella, relatively broad fixed cheek, fairly anterior eyes and subparallel anterior sutures. Although a precise comparison is deferred to a later occasion, it is more closely related to an undescribed genus (*Iwayaspis*) from the Machari formation. It is intermediate between the Asaphidae and Ceratopygidae, principally different from the latter family in the absence of a pair of spines on the pygidium and from the former in the possession of nine segments in thorax.

    Yüpingia niobiformis LU (Text-fig. 10b) is a contemporary with *Charchaqia* and early Upper Cambrian in age, because it is found in East Kweichow toge-
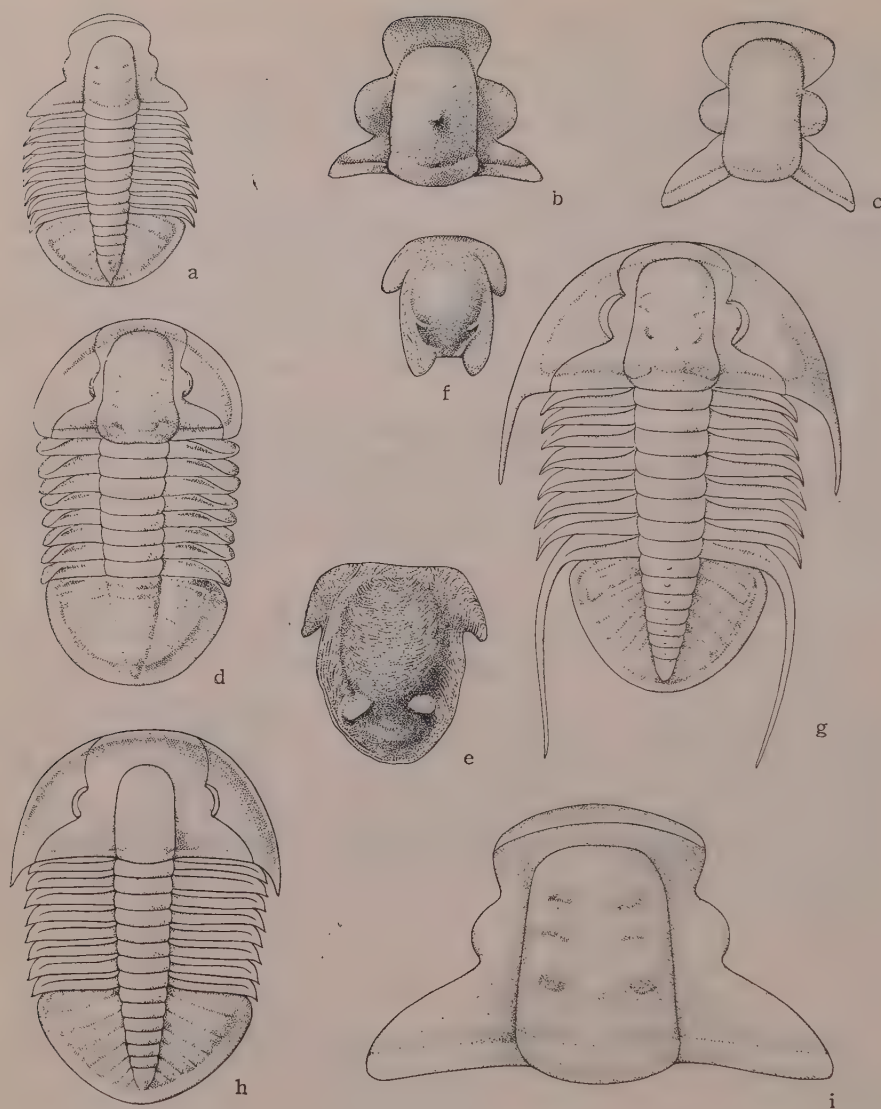
Figure 10.

a.   *Eoasaphus superstes* (LINNARSSON)
b.   *Yüpingia niobiformis* LU
c.   *Metoptogyrus grangeri* RAYMOND
d, e.   *Niobella aurora* WESTERGÅRD
f, g.   *Promegalaspides kinnekullensis* WESTERGÅRD
h.   *Charchaqia norini* TROEDSSON
i.   *Norinia convexa* TROEDSSON

ther with *Eugonocare* and *Prochuangia*. It is recongnized by JAANUSSON as a member of his subfamily, Niobinae, but not the less allied to late Middle Cambrian *Haniwoides* on one side and to Lower Ordovician *Metoptogyrus* (Text-fig. 10c) on the other. In my opinion *Haniwoides* is the closest relative to it. Simply it differs from *Haniwoides* by the prominent median tubercle, rounded

anterior outline of the glabella and distinct occipital furrow. Lower Ordovician *Metoptogyrus* can be distinguished from *Yüpingia* by the relatively longer glabella contracted at the midlength, absence of the median tubercle and the more expanded preglabellar area. *Columbicephalus* is another Lower Ordovician ally which however, has the distinct isoteli-form suture.

In Sweden *Eoasaphus* occurs in the *Orusia lenticularis* zone. *Eoasaphus* (or *Anorina*) of which *Liostracus* (?) *superstes* LINNARSSON (Text-fig. 10a) is monotypic, has the cranidium and pygidium closely related to those of *Norinia convexa* (Text-fig. 10i) in the conical glabella and three pairs of short lateral furrows. Although the eyes are located more anteriorly and the postero-lateral limb of the fixed cheek is larger in the latter, I think that the two genera belong to the same lineage. According to TROEDSSON the hypostoma associated with *N. convexa* resembles that of *Symphysurus*. No hypostoma is known of *Eoasaphus*. JAANUSSON referred *Norinia* to the Niobinae.

Niobella (Text-figs. 10d, e) and *Promegalaspides* (Text-figs. 10f, g) occur in Sweden in the *Peltura* zone and possibly in the *Acerocare* zone. The latter for which JAANUSSON instituted the Promegalaspidinae has the cranidium resembling those of *Niobe* and *Niobella*, but the free cheek carries a genal spine and the pleura of the eighth thoracic segment is prolonged into a spine. The hypostoma is sinuated in posterior in *Promegalaspides*, but entire in *Niobella*. LOMOVITSKAJA (in KHALFIN, 1955) erected four new species of *Promegalaspides* for cranidia from the upper Tremadocian of Siberia. It is desirable to search a spiniferous thoracic segment to confirm their generic reference. At any arte it is interesting to see that one or two post-cephalic segments are spiniferous in this subfamily or the Ceratopygidae, although such a segment is in thorax in the former and in pygidium in the latter.

In short, *Niobella* and *Eoasaphus* belong to the Niobinae; *Promegalaspides* and *Charchaqia* are related to the Niobinae as well as the Ceratopygidae in one or the other character; *Yüpingia niobiformis* is, as suggested by its specific name, allied to the Niobinae, but at the same time to the the Anomocaridae. There is no Upper Cambrian asaphid or asaphoid very intimate to the Dikelokephalinae or Dikelocephalidae.

Subfamily Isotelinae ANGELIN, 1854

Genus *Asaphellus* CALLAWAY, 1877

Asaphellus tomkolensis KOBAYASHI, 1934

Plate XIV, Figures 15–24.

1934. *Asaphellus tomkolensis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9*, p. 549, pl. 4, figs. 1–4, (?) 5–7.
1934. *Asaphelllus* aff. *gyracanthus* KOBAYASHI, *Ibid.* p. 551, pl. 4, figs. 8–11.
1934. *Asaphellus* (?) sp. KOBAYASHI, *Ibid.* p. 553, pl. 4, figs. 13–14.

Although no complete dorsal shield has as yet been discovered, the pygidia which occur in the Bunkoku formation are not truncated on the posterior side

and their outline is semi-circular, like those of *Asaphellus* aff. *gyracanthus* and *Asaphellus* (?), sp. Therefore it is probable that the trapezoidal pygidium previously referred to this species belongs to some other species. In a pygidium from loc. 248 (fig. 19) the marginal border is remarkably depressed. The border is not so angulated along the inner margin in another pygidium from loc. 249 (fig. 20). In an immature pygidium from loc. 252 (fig. 23) anterior two rings and pleural ribs are quite distinct. Seeing the variability, it is considered that the relatively long pygidium of *Asaphellus* (?) sp. may be involved in this species.

At loc. 239 a hypostoma (fig. 22) was found together with a pygidium of this kind (fig. 21) to which a posterior thoracic segment is attached. Its posterior outline is entire and somewhat produced at the middle point. The central body is embraced by a depressed lateral border on each side. The anterior aspect is, however, obscure in this specimen. Another hypostoma from loc. 206 (fig. 16) is nearly perfect, but the very posterior median projectile is unpreserved.

It is fortunate to find at Shi 2 (fig. 15) the same kind of hypostoma having a pair of maculae and a small projectile at the middle of the posterior border as seen in the hypostomata of *Asaphellus homfrayi* (Lake, 1942) and *Asaphellus catamarcensis* (Harrington and Leanza, 1957). It is accompanied by the cranidium and other parts of *tomkolensis*. A further confirmation is the find of a hypostoma at Doten (fig. 24). Though it is imperfect, it agrees with the preceding in the observable characteristics. Therefore it is quite reasonable at present to assign the above hypostoma to this species.

Occurrence :—Tomkol shale at Dotenri, Shi 2, and other localities. Detached carapaces of this species were found in the Bunkoku formation at various localities, 206, 239, 248, 249, 252, 282, etc. In the *Yosimuraspis* zone, though rare, it is represented by the cranidium from loc. 282 which is quite typical of this species (fig. 17).

Order Phacopida Salter, 1864

Family Pliomeridae Raymond, 1913

Subfamily Pilekiinae Sbuzy, 1955

Genus *Metapilekia* Harrington, 1938

Metapilekia martellii (Kobayashi), 1934

1934.   *Metopolichas* (?) *martellii* Kobayashi, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9*, p. 565, pl. 7, fig. 1.

Since I had described this pygidium, I was strucked to find its close resemblance with the pygidium of *Metapilekia bilirata* Harrington, 1938. These two in addition to the pygidium provisionally assigned to *Dikelocephalus* (?) *corax* Billings bear so many characters common among them that their congenity is forcefully suggested. Namely, they have subrectangular first pleural ribs by which their general outline looks subquadrate. The three pleural ribs

are all flat and prolonged back into spines. The axis is conical and composed of three rings and a terminal lobe.

M. martellii appears to have the fourth pleural rib, though it is simple and rudimentary. The pleural and interpleural furrows are developed in the three others. In *M. bilirata* the axial lobe is much broader and the lateral angle of the first pleural rib more rounded than in *martellii*.

Least possibility remains for *martellii* to belong to the Lichidae not only because of its morphology but also because no lichid has as yet been found in Korea.

Occurrence :—Protopliomerops zone of Sesong-ni (Saishori).

Metapilekia sp. nov.

Plate XIII, Figure 26.

Though fragmentary, the close alliance of this pygidium to *Metapilekia martellii* is hardly deniable, because it has more than three flat pleural ribs each bearing a pleural furrow. The second rib is strongly suggestive of its rectangular bent at about the middle. It is however, specifically different from *martellii* because the pleural part is much broader in comparison to the axial part. If it is not a *Metapilekia*, it may belong to *Pilekia*.

*Occurrence :—*Bunkoku formation at loc. 232.

Genus *Protopliomerops* KOBAYASHI, 1934

Protopliomerops punctatus KOBAYASHI, 1934

Plate XIII, Figures 14–15.

1934. *Protopliomerops punctatus* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9*, p. 572, pl. 7, figs. 4–5.

A small cranidium from loc. 252 has a subquadrate glabella, three pairs of profound lateral furrows, small eyes close-set to the first furrows and strongly punctate free cheeks. With this specimen one can get a better concept of the cranidium than the previous restoration. The glabella exclusive of the neck ring is nearly as long as broad and its anterior margin less arcuate than presumed on that occassion. The three lateral furrows are all straight, oblique, parallel to one another and extending more than one third the breadth of the glabella. Its test is smooth or very sparsely granulate.

Another specimen from loc. 250 which is ill-preserved, is similar in size to the type cranidium from Tongjomni (Dotenri). The cheeks of these specimens are similarly punctate, but the lateral and posterior borders smooth and marginal furrows fairly strong. In the two cranidia before hand the genal angle is 40 to 50 degrees. The genal spine of moderate length is projected in the same direction with the lateral border.

The glabella of this species is shorter than those of *P. seisonensis, P. granulatus* or *Koraipsis spinus*. In the texture of the glabella and cheeks and

in the size and position of the eyes this species fits better with *Koraipsis spinus* than these species of *Protopliomerops*.

Occurrence:—Bunkoku formation at Locs. 252 and 250; *Protopliomerops* zone of Dotenri.

Genus *Koraipsis* Kobayashi, 1934

1934. *Koraipsis* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9,* p. 574.

Type-species:—*Koraipsis spinus* Kobayashi, 1934, monotypic.

Remarks:—This genus is known only of the cranidium which looks similar to *Protopliomerops*. The unique feature of this genus among cheirurids is the frontal spine issuing from the glabella which is so distinct that it leaves no difficulty of recongnizing its generic independence. As noted already, the agreement of the type-species with *Protopliomerops punctatus* in many aspects suggests that the latter may be the second species of the genus, if it bears such a spine.

Distribution:—Lower Ordovician; South Korea.

Koraipsis spinus Kobayashi, 1934

Plate XIII, Figures 16a-b, Text-figure 11.

1934. *Koraipsis spinus* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3, Pt. 9,* p. 574, pl. 8, fig. 1.

The cranidium from loc. 221 consists of an internal and external mould. Compressed laterally, the glabella is elongated and subcarinated along the axis; lateral furrows are long and assume greater obliquity than they have originally been. The glabella is quadrate, but somewhat rounded in front. Eyes are close-set to the first lateral furrows which start from the antero-lateral angles of the glabella. Its frontal lobe whence the stout spine issues is relatively small. Fixed cheeks are strongly punctate, but not the marginal borders. Some minute tubercles are found scattered on the glabella.

Occurrence:—Bunkoku formation at Loc. 221; *Clarkella* zone of Sesong-ni (Saishori).
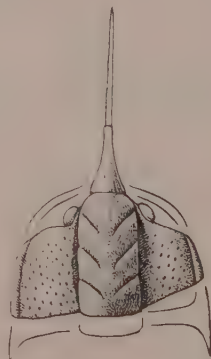
Figure 11. *Koraipsis spinus* Kobayashi

Genus *Hintzeia* Harrington, 1957

Hintzeia glabella Kobayashi, new species

Plate XIII, Figure 32.

Description:—Glabella outlined by profound dorsal furrows, subquadrate, almost as long as broad, moderately tapering forward and subrounded in front,

more or less flattish on top and provided with three pairs of lateral furrows which are parallel to one another and equally strong; anterior furrow starting a little inside of antero-lateral angle; posterior furrow abruptly bent back near axis and meets with broadly arcuate occipital furrow; neck ring thickened mesially, but its posterior margin is straight; fixed cheek probably narrower than glabella, gently convex, nearly as high as glabella; eyes opposed at middle glabellar furrows and connected with antero-lateral angle of glabella by strong eye-ridge; frontal border flat, slant forward, delimited inside by a deep furrow on which the frontal lobe of glabella is somewhat protruded; test smooth.

Comparison :—The cheek is so imperfectly preserved that no statement can be given of the facial suture. Nevertheless, this species is diagnostic of *Hintzeia*. *Protopliomerops aumula* Hintze which is the type-species differs from this in the more arcuate and convex frontal border, smaller frontal lobe and weaker anterior furrow of the glabella, more anterior position of the eye and granulate test.

Occurrence :—Bunkoku formation at Loc. 100906.

Pliomerid, gen. et sp. indt.

Plate XIII, Figures 33-34.

Small pliomerid thorax composed of 11 or 12 segments; pleurae a little broader than axial rings, bent back in distal half or a third; anterior pleural rib strong; pleural furrow weak.

It is smaller than the thorax which was referred to *Protopliomerops seisonensis*. It may belong to *Hintzeia glabella*, as it is the only small pliomerid.

Occurrence :—Bunkoku formation at Locs. 93002 and 93006.

Hypostoma, fam. gen. et sp. indt.

Plate XIV, Figure 3.

An external mould of a hypostoma is mainly occupied by a large ovate fairly convex central body in the posterior part of which a pair of narrow and shallow lunate grooves are opposed with the convexity on the anterior and inner side. The body is surrounded by a narrow rim, but on its antero-lateral side there is a triangular wing. The anterior margin of the hypostoma which is separated from the central body by a groove, is erect and arcuate and forms the anterior margin of the wing on the lateral side.

The hypostoma resembles that of *Apatokephalus hyotan*, although they are somewhat different in outline.

Occurrence :—Associated with some plates of *Plumulites* cfr. *primus*, but no trilobite on the same slab. However, *Apatokephalus hyotan, Dikelocephalus parva, D. conica* and *Asaphellus tomkolensis* are polymeric trilobites collected from Loc. 248 where the slab was procured.

Class Crustacea (?)

Subclass Branchiopoda (?)

Order Ribeirida KOBAYASHI, 1954

Family Ribeiridae KOBAYASHI, 1933

I have once considered that the Ribeiridae and Eopteridae are synonymous, because *Eopteria* which is the type-genus of the latter was included in the former. Now I think, however, the Ribeiridae must stand for the group of *Ribeiria* having the smooth carapace, entire in outline. Most others of the order have radial sculptures on the test or one or two wings are often protruded along the dorsal margin. *Ribeiria* and *Ribeirella* have two clavicles, instead of one, but the posterior one is generally a thickening along the postero-dorsal margin which is not always distinct nor protruded ventrally.

Incidentally, *Aluta paiensis* ENDO and its variety, *tenuis* ENDO (1937) from the late Upper Camprian at Paichiashan, Chinchiachengtzu, Liaoning, (China) is extraordinarily large for *Aluta* and do not show any characteristic of the genus. On the other hand their size, outline and other aspects suggest their being *Wanwanias* closest to *W. cambrica* which was also procured from the same formation at Paichaishan hill (KOBAYASHI, 1933).

Genus *Ribeirella* SCHUBERT and WAAGEN, 1903

Ribeirella subcircularis KOBAYASHI, new species

Carapace almost circular, as long as high and gently convex. Internally, anterior clavicle of moderate size, triangular and pointed toward the center of the valve; the other clavicle which is a thickening of the rounded postero-dorsal margin, is protruded a bit ventrally at the extremity.

The test is unpreserved. The specimen, however, suggests that a shallow sinuation may exist in front of the umbo. It is certain that the other margins are well rounded. In the subcircular outline this species closely resembles *Ribeirella crassa* THORAL from the lower Arenig of South France and *Ribeirella* sp. (1936) or Bivalve indt by ETHERIDGE from the Table Cape conglomerate in Tasmania. In the French form the carapace is more convex and the anterior clavicle narrower. In the Tasmanian form the posterior clavicle is as prominent as the anterior one.

Occurrence :—Loc. 193 with *Clarkella vulgaris*.

Subclass Cirripedia (?)

Genus *Anatifopsis* BARRANDE, 1872

This is a peculiar fossil of unkown taxonomic position. Because of its resemblance with terga of *Lepas*, BARRANDE referred it to the Cirripedia. This opinion was later upheld by CHAUVAL. BROILI (1924) placed it provisio-

nally in the Lepidocoleidae of the Cirripedia. WITHERS (1926), however, proposed Machaeridia to include this family as well as the Turrilepadidae and emphasized its alliance to the Echinodermata. THORAL (1935) on the other hand brought *Anatifopsis* to the Phyllopoda.

BARRANDE described four species of *Anatifopsis* as follows:

1. *A. prima* BARRANDE from d1
2. *A. acuta* BARRANDE from d2
3. *A. bohemica* BARRANDE from d3–4
4. *A. longa* BARRANDE form d4

The genus is best represented by *A. prima* which is not essentially different from the Korean forms in the presence of two internal clavicles divergent ventrally from the anterior end of the dorsal margin. The outline of *prima* is somewhat quadrate, or better to say, triangular, elongated laterlly and far more elongated than that of the Korean forms and even pointed behind. An additional distinction lies in the subdorsal narrow and very long depressed area and much greater convexity of the shell.

The triangular outline is more typically represented by *A. acuta*. *A. longa* looks quadrate, but protruded postero-ventrally. In outline *A. bohemica* is the nearest to the Korean forms, but still the valve is divided into a subdorsal, median and anterior area by obtuse angulations.

THORAL described the following two species from the Montagne Noire, South France.

5. *A. trapeziformis* THORAL common at the top of *Asaphelina barroisi* zone and rare at the base of *Taihungshania* (i. e. *Miquelina*) *miqueli* zone. Similar to *A. bohemica*, but more trapezoidal, having parallel dorsal and ventral margins.
6. *A. escandei* THORAL, common in *miqueli* zone, more qudarate and cylindrical than *A. trapeziformis*.

Compared to these European species, the Korean forms have the outlines evidently higher, shorter and more quadrate. There is no submarginal groove or carina internal or external. The convexity of the shell is moderate and never so strengthened as that of *A. prima* and some other species.

Anatifopsis cocaban KOBAYASHI, new species

Plate XIII, Figures 2–6.

Shell bivalved, subquadrate; anterior margin semi-circular. Internally, two clavicles extending ventrally from the anterior end of the dorsal margin.

On a specimen (Fig. 6) from loc. 248 there are two valves smooth externally, but fine growth lines are closely impressed on the internal surface. These lines run parallel to the ventral and posterior margins. The right valve on the left side of the observor shows a weak sinuation along the posterior margin. Supposing it to be an arthropod, its abdomen is inferred to have been protruded therefrom backward. The anterior margin of the

other valve is somewhat recurved, taking the aspect of a narrow rim.

As seen in the internal moulds from locs. 233 and 249, there are two strong grooves which are impressions of internal clavicles. The section in front of the anterior clavicle is narrow and lunate. In a specimen in fig. 4, it is crossed by a weak ridge or groove. The next section is long, triangular and broader than the preceding. The posterior clavicle is as a rule stronger than the anterior one.

In an internal mould (fig. 3) the second or posterior clavicle is represented by a deep groove and provided behind it with a narrow groove, i. e. a ridge on the mould.

Occurrence :—Widely distributed in the Bunkoku formation and collected at Locs. 248, 233, 93004 and 100101.

Anatifopsis truncatum KOBAYASHI, new species

Plate XIII, Figure 1.

This is distinguished from the preceding species by the carapace-outline which is diagonally truncated on the postero-ventral side and distinctly sinuated to the ventral side near the point where the posterior clavicle terminates. Growth lines are clearly impressed on the other side.

Occurrence :—Bunkoku formation at Loc. 252.

Phylum Echinodermata

Class Cystoidea VON BUCH

Cystoid, gen. et sp. indt.

Plate XIV, Figure 27.

Small rhombic plate on which deep relatively broad grooves radiate toward the angles from the fairly large central depression.

Occurrence :—Bunkoku formation at Loc. 252.

Class Machaeridia WITHERS

Family Turrilepadidae CLARKE

Genus *Plumulites* BARRANDE, 1872

Plumulites cfr. *primus* KOBAYASHI, 1934

Plate XIII, Figure 17.

1934. Cfr. *Plumulites primus* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 3,*
     Pt. 9, p. 526, pl. 2, figs. 1-3.

The triangular outline of this keeled plate is fairly similar to that in fig. 2, pl. 2, 1934, but more asymmetrical and twisted. The inner margin is remarkably concave. The basal margin is distinctly sinuated in the median part, but neither the longitudinal fold nor growth lines are well impressed.

Hence its identification cannot be definite.

Occurrence :—Bunkoku formation at Loc. 248.

Plumulites sp. nov.

Plate XIII, Figures 18–19.

Two kite-shaped plates, poorly preserved, but quite distinctive from the known plates of *Plumulites* from Korea in its slender outline.   In the better one in fig. 18, the length corresponds to almost two and a half of the breadth. It is gently curved and grooved mesially, but nearer to the convex than the other side.   The two sides of the groove are marked by fine striae which form an angle of about 100 degrees. • The other plate is also long, slightly curved, mesially grooved and striated on its two sides.

Occurrence :—Bunkoku formation at Locs. 206 and 233.

Phylum Prochordata

Class Graptolithina Bronn, 1846

Shiraki was the first to discover graptolites in Korea.   In 1922 he found them at Hwangii-ri, Sangjang-myŏn, Samchŏk-gun, Kwanwŏn-do. (江原道三陟郡 上長面黄池里). In 1934 I made a study on the graptolites from the Chikunsan shale at Hwangii-ri and Makkol, Sangdong-myŏn, Yŏngwŏl-gun, Kwangwŏn-do, (江原道寧越郡上東面莫洞) which were collected by Shiraki and myself respectively.   There were *Diplograptus* (*Amplexograptus*) *preexcavatus* Lapworth and *Dicellograptus* or *Dicranograptus* sp. indt.   Shimizu and Obata (1935) reported the occurrence of *Climacograptus* cfr. *bicornis* (Hall), ? *Diplograptus* (*Glyptograptus*) *teretiusculus* var. *siccatus* Elles and Wood and ? *Diplograptus* (*Glpytograptus*) *teretiusculus* var *kansuensis* Grabau from the same shale at Chiktong-ni and Tumu-kol (稷洞里, 斗務洞) both in Sandong-myŏn, but none of them was described or illustrated.

The graptolite which Hukasawa discovered in the Bunkoku formation at Paeg'un-do (Hakununudo) and Chongbou-ri (Shokyuri) were *Dictyonema* cfr. *flabelliforme* and *Clonograptus* (?) sp.

The graptolite shale must be Tremadocian and approxiamate in age to the *Dictyonema flabelliforme* zone of the Yehli limestone in Hopei, North China and the *Dictyonema* shale near Ichang, Hupeh, Central China.

Order Dendroidea Nicholson, 1872

Family Dendrograptidae Roemer in Frech, 1897

Genus *Dictyonema* Hall, 1850

Dictyonema cfr. *flabelliforme* Eichwald, 1840

1942. *Dictyonema* cfr. *flabelliforme* Kobayashi and Kimura, *Japan. Jour. Geol. Geogr. Vol. 18*, p. 308, pl. 29, figs. 1–3.

Occurrence:—Bunkoku formation at Locs. 91405 and 101909.

Family Dichograptidae Lapworth, 1873

Genus *Clonograptus* Hall and Nicholson, 1873

Clonograptus (?) sp.

1942. *Clonograptus* (?) sp. Kobayashi and Kimura, *Japan. Jour. ·Geol. Geogr. Vol. 18*, p. 309, pl. 29, figs. 4–5.

Occurrence:—Bunkoku formation at the preceding localities.

Problematicum

Coprolites (?)

Plate XIV, Figures 25–26.

A narrow strip in fig. 25 is constricted at short intervals nearly equal to the breadth of the strip. It is, however, thickened at an end where are crowded small segments which are narrower, but relatively long.

Another strip in fig. 26 is thicker than twice the preceding, but the constriction is obscure and irregular.

These strips take irregular courses not in an horizontal place. It is certain that they are neither remains of organisms by themselves, nor cralwing impressions. They are probably excrements left behind when animals crawled.

Occurrence:—Bunkoku Formation at Locs. 100101 and 101909.

Postscript

Liaoningaspis taitzehoensis Chu, 1959, is so astonishingly similar to *Monkaspis daulis* that they are considered probably congeneric with each other. The former is the type-species of *Liaoningaspis* Chu, 1959, which was collected from the *Blackwelderia paronai* zone of the Yentai and Penhsi coal-fields, Liaoning. It is specifically distinct from the latter which is the type-species of *Monkaspis*, in the weakness of the lateral furrows on the glabella and the eye-ridges which start a little behind the anterior margin of the glabella in *taitzehoensis*, while they begin at the lateral ends of the margin in *daulis*. The pygidium is broader, the pleural lobes are less segmented and the lateral margin has only two anterior serrations in *taitzehoeneis*, but more than three serrations are present in *daulis*.
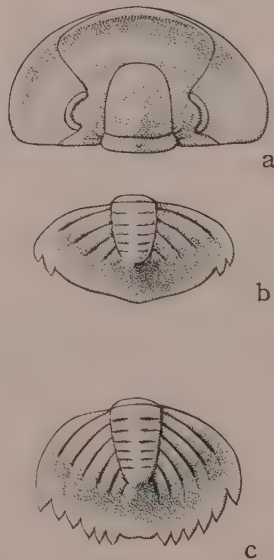
Figure 12.
a–b. *Liaoningaspis taitzehoensis* Chu
c. *Kushanopyge serrata* Chu

In the mode of serration *M. daulis* agrees better with *Kushanopyge serrata* CHU, 1959, also from these coal-fields.   The species was founded on the pygidium and made the type-species of *Kuhsanopyge*.   Compared with *daulis*, the anterior margin is more arcuate, and the concave marginal brim more developed in *serrata*.   Therefore it is evident that they are two distinct species, but it is a question that they represent separate genera.   If *Kushanopyge* is not a synonym with *Monkaspis*, *Monkaspis* is the most intimate genus to *Kushanopyge*.

CHU Chao-ling (1959), Trilobites from the Kushan Formations of North and Northeastern China.   *Mem. Inst. Pal., Acad. Sinica, No. 2.*

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See also the references on pages 220–221.

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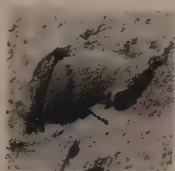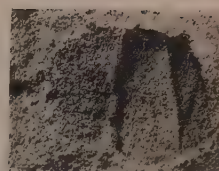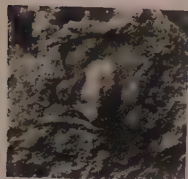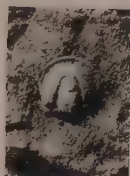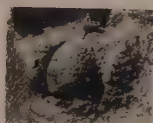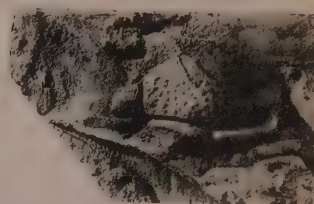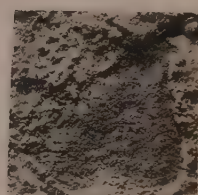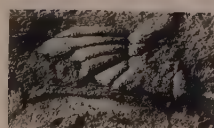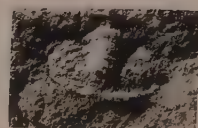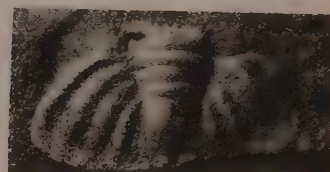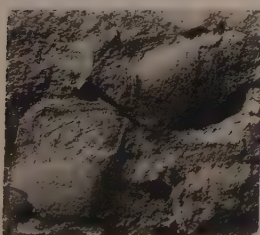
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Plate XIV

Explanation of Plate XIV

JURASSIC INOCERAMIDS IN JAPAN*

By

Itaru HAYAMI

With Plates XV–XVIII

Abstract

Jurassic inoceramids occur fairly commonly at various localities in Japan. They seem important for domestic and international correlation, but no comprehensive palaeontological study was published, and accordingly, their stratigraphical application was unsatisfactory. In this paper I describe 26 Japanese forms including 10 new species based on the collections of the Geological Institute, University of Tokyo, which came from various horizons in Nagato, Kitakami and Hida regions, and show a provisional classification of the Jurassic Inoceramidae. My available material can be classified into the following groups.

Parainoceramus VORONETZ, 1936 (upper Triassic—Bajocian)

Inoceramus SOWERBY, 1814 (upper Lias—upper Cretaceous)

    Group of *I. polyplocus* ROEMER (Aalenian—Bathonian)

    Group of *I. fuscus* QUENSTEDT (Toarcian—Oxfordian)

    Group of *I. lucifer* VON EICHWALD (Bajocian)

    Group of *I. retrorsus* KEYSERLING (Bathonian—Oxfordian)

    Group of *I. galoi* BOEHM (Callovian—? Cretaceous)

    Group of *I. neocomiensis* D'ORBIGNY (? Oxfordian—Albian)

    Incertae sedis

Since many of the famous European species were established very early, specific identification of inoceramids in other continents often meets with much difficulty. Nevertheless, several Japanese specimens are certainly comparable with European, Arctic or Australasiatic species. In most cases their occurrences agree well with the chronology hitherto shown by ammonites, and it is concluded that inoceramids constitute an important pelecypod group for biostratigraphy not only in the Cretaceous but also in the Jurassic.

Contents

Introduction

Japan seems an important field for the study of the Inoceramidae, since they are fairly common not only in the Upper Cretaceous but also in the Jurassic strata at various localities. Since KOBAYASHI (1926) had described *Inoceramus utanoensis* and *Inoceramus ogurai* from the Dogger-Malm Utano formation of the Toyora group in West Japan, the occurrences of *Inocerami* at various horizons of Japanese Jurassic were announced by many stratigraphers. In the Toyora area INOUYE, KOBAYASHI, TORIYAMA (1938), MATSUMOTO and ONO (1947) collected rich material through their field works. In Kitakami region of Northeast Japan various Lias and Dogger species were known by KOBAYASHI, FUKADA, YAMASHITA, MORI (1949) and SATO's fossil-hunting. In the Hida plateau of Central Japan, OGASAWARA, MAEDA (1952b), HAMADA and others found some characteristic *Inoceramus*-bearing strata in the Jurassic and Cretaceous Tetori group. These collections are now mostly preserved in the Geological Institute, University of Tokyo. KUDO intended to classify and describe them, but did not accomplish the work.

Inoceramids bear special importance for Jurassic and Cretaceous stratigraphy, but their classification is not easy and now somewhat confused. The Jurassic species, though not so numerous as the Cretaceous ones, are invaluable for the phylogeny of the Inoceramidae, but they are unfortunately insufficiently investigated. In this paper I describe the following 26 forms including 10 new species in the institute collection which may cover most Jurassic inoceramids hitherto known in this country.

Parainoceramus lunaris HAYAMI, new species
Parainoceramus matsumotoi HAYAMI, new species
Parainoceramus cf. *matsumotoi* HAYAMI
Parainoceramus sp. ex gr. *matsumotoi* HAYAMI
Parainoceramus sp. indet.
Inoceramus (*Mytiloceramus*) *karakuwensis* HAYAMI, new species
Inoceramus morii HAYAMI

Inoceramus sp. ex gr. *fuscus* QUENSTEDT
Inoceramus cf. *nitescens* ARKELL
Inoceramus hamadae HAYAMI, new species
Inoceramus hashiurensis HAYAMI, new species
Inoceramus cf. *lucifer* VON EICHWALD
Inoceramus utanoensis KOBAYASHI
Inoceramus ogurai KOBAYASHI
Inoceramus sp. ex gr. *galoi* BOEHM
Inoceramus maedae HAYAMI, new species
Inoceramus maedae HAYAMI, var. a
Inoceramus maedae HAYAMI, var. b
Inoceramus furukawensis HAYAMI, new species
Inoceramus (s. l.) *kudoi* HAYAMI, new species
Inoceramus (s. l.) *fukadae* HAYAMI, new species
Inoceramus (s. l.) a sp. indet.
Inoceramus (s. l.) b sp. indet.
Inoceramus (s. l.) c sp. indet.
Inoceramus (s. l.) d sp. indet.
Inoceramus (?) *naganoensis* HAYAMI, new species

Since I am not in a position to examine the type-specimens of foreign species, I find it difficult to classify them systematically on a firm basis. The taxonomic notes discussed in this paper are, therefore, provisional.

Acknowledgements

Distribution of Domestic Jurassic Inoceramids

Before taxonomic discussions, previous studies and distribution of Jurassic inoceramids are briefly reviewed. Japanese Jurassic inoceramids are so far known in three regions, namely Nagato region of West Japan, Kitakami mountainland of Northeast Japan and Hida plateau of Central Japan. In the first and second regions upper Lower and Middle Jurassic primitive species are well represented, while Upper Jurassic species seems to be confined properly to the last region. (Table 1).

1) Nagato region

According to MATSUMOTO and ONO (1947) and ARKELL (1956) the Toyora group in western Yamaguchi Prefecture can be biostratigraphically divided into

the following beds.

	upper part (Bajocian—? Callovian)	
	Ut *Holcophylloceras* bed	
Utano formation	Uz barren	(Bajocian)
	Uh *Hammatoceras* bed	
	Ub *Haugia* bed	
	Up *Posidonia* bed	
	Na *Dactylioceras* bed	
	Nd *Dactylioceras-Hidoceras* bed	(Toarcian)
Nishinakayama formation	Ng *Protogrammoceras* bed	
	Ne *Fontanelliceras* bed	(up. Pliensbachian)
Higashinagano formation	(Hettangian—Sinemurian)	

It has long been known that the Nishinakayama shaly formation yields some small inoceramids, which were once considered as mytilids, altogether with upper Liassic ammonites. MATSUMOTO and ONO (1947) listed *Inoceramus* spp. from Ne, Ng and Nd beds. Among TORIYAMA's and my collections *Parainoceramus lunaris*, n. sp. from Ne and *P. matsumotoi*, n. sp. and some allied forms from Nd bed are distinguished. This fauna may bear some alliances to those of the Toarcian and Aalenian of Europe and Caucasus. Large forms of *Inoceramus* appear in this area at first in Uh bed of the Utano formation, and they are obviously different from Nishinakayama forms. *Inoceramus* sp. ex gr. *fuscus* QUENSTEDT from this horizon is apparently similar to the Bajocian species from Europe. *Inoceramus utanoensis* and *I. ogurai* were described by KOBAYASHI from the upper part of the Utano formation. The fauna is not exactly dated, but its age is probably Bathonian or later, considering that the formation is fairly thick and that the occurrence of *Onychiopsis elongata* was reported from the horizon. A small specimen of an indeterminable inoceramid belonging to the old collection of this institute is labelled that it came from " Yoshimo ". The Yoshimo beds must be, as clarified by KOBAYASHI and SUZUKI (1939), Wealden brackish deposits, and its exact locality is unknown at present.

2) Kitakami region

The Jurassic of the western belt of the south Kitakami mountainland in Miyagi Prefecture is best typified by the sequence of Shizukawa area (MABUTI, 1933; INAI, 1939; MATSUMOTO, 1953; ONUKI, 1956; SATO, 1957).

	Sodenohama formation (? Kimmeridgian—Tithonian)
Hashiura group	Arato formation (Bajocian—Kimmeridgian)
	Aratozaki formation (Bajocian)
Shizukawa group	Hosoura formation (Sinemurian—Aalenian)
	Niranohama formation (Hettangian)

The Hosoura formation consists mainly of arenaceous shales of the first innundation phase, and yields *Inoceramus* (s. l.) *kudoi*, n. sp. altogether with *Hammatoceras*, *Tmetoceras* and *Graphoceras* in the upper part (Hh zone by SATO, 1957). The basal part of the Bajocian Aratozaki sandy formation contains some lenticular fossil beds where *Inoceramus morii* HAYAMI and *Parainoceramus* sp. coexist with *Trigonia sumiyagura* KOBAYASHI and KASENO, *Camptonectes* cf. *auritus*

(SCHLOTHEIM) and *Ludwigia*-like ammonite, as I noted elsewhere (HAYAMI, 1959a). The Arato shaly formation showing the second innundation facies bears *Inocerami* at several horizons in Shizukawa and Hashiura areas. Most specimens are too fragmental to be determined specifically, but I distingnished *Inoceramus hashiurensis*, n. sp. and *I.* sp. ex gr. *galoi* BOEHM in MORI's collection. Because of the scarceness of guide fossils and well defined key beds, the biostratigraphy of this formation is still obscure, but the sedimentation is considered to have continued from Bajocian to Kimmeridgian in view of the occurrences of *Cadomites* (BANDO, 1958) and *Idoceras* (ARKELL, 1956). MATSUMOTO (1953) listed *Inoceramus* sp. from the overlying Sodenohama formation whose age is presumed Kimmeridgian to Tithonian.

The eastern belt of the Kitakami Jurassic comprises the Ojika group in Ojika peninsula and the Karakuwa and Shishiori groups in Kesen area. FAKADA (1947, MS)* distinguished "*Inoceramus* bed" in the Kodaijima sandy formation at the neck of the peninsula. The inoceramid is somewhat aberrant and named here *Inoceramus* (s. l.) *fukadae*. The age is probably upper Lias or Bajocian since the bed is adjacent to the *Trigonia sumiyagura* bearing sandstone. Besides, FUKADA collected a specimen at the west of Momonoura, whose mother rock is correlative to the Tsukinoura formation (probably Bajocian) according to ONUKI (1956). In Kesen area SHIIDA (1940) listed *Inoceramus* sp. from the Kosaba formation which may be identical with *Inoceramus morii* from the Bajocian Aratozaki formation. *Inoceramus karakuwensis*, n. sp. and *Inoceramus* cf. *lucifer* VON EICHWALD occur in the overlying Tsunakizaka shaly formation. SHIIDA referred its age to Lias, but later SATO (1956) ascertained with *Stephanoceras* that the black shales are correlated to the lower part of the Arato formation. The large dimensions of the two *Inocerami* and their resemblances respectively with *Inoceramus polyplocus* from the Bajocian of Europe and *I. lucifer* from the Bajocian of Arctic region may support SATO's opinion. Besides, an *Inoceramus*-like pelecypod is found in the Tithonian-Berriasian Kogoshio formation of the Shishiori group.

3) Hida region

No inoceramid was ever collected from the Liassic Kuruma group. The stratigraphy of the Jurasso-Cretaceous Tetori group has been recently promoted by MAEDA (1954a, b, etc.) and some others, and the occurrences of *Inocerami* were announced at various localities. According to MAEDA the succession of the Tetori group is typified in Kuzuryu and Makito areas as follows:

Kuzuryu area in Fukui Prefecture

Akaiwa subgroup

Itoshiro subgroup
{
Nochino formation
Izuki formation
Ofuchi formation
Ashidani formation
Yambara formation
}

---

* FUKADA's result was briefly cited by KOBAYASHI (1948, p. 273).

Kuzuryu subgroup $\left\{\begin{array}{l}\text{Yambarazaka formation} \\ \text{Kaizara formation} \\ \text{Tochimochiyama formation} \\ \text{Oidani formation} \\ \text{Shimoyama formation}\end{array}\right.$

Makito area in Gifu Prefecture

"Akaiwa subgroup"

"Itoshiro subgroup" $\left\{\begin{array}{l}\text{Amagodani formation} \\ \text{Daikokudani formation} \\ \text{Otaniyama formation}\end{array}\right.$

"Kuzuryu subgroup" $\left\{\begin{array}{l}\text{Mitarai formation} \\ \text{Nonomata (formerly Akaboke) formation} \\ \text{Ushimaru formation}\end{array}\right.$

The Kaizara formation composed of transgressive black silty shales contains *Inoceramus hamadae*, n. sp. at Shimoyama and *Inoceramus* cf. *nitescens* ARKELL and *I.* (?) *naganoensis* at Nagano. Its age has been considered to be Callovian or Oxfordian on the basis of *Seymourites* and perishinctids (YOKOYAMA, 1904; KOBAYASHI, 1947; ARKELL, 1956). *Inoceramus* cf. *nitescens* is similar to the type specimens from the Corallian of England. The Mitarai shaly formation, which is a solitary marine formation in Makito area, has been correlated to the Kaizara formation. But the pelecypod fauna of the Mitarai, as I reported before (HAYAMI, 1959b, c) contains some allied forms to Lower Cretaceous as well as Upper Jurassic ones in Europe and boreal regions. The inoceramid fauna is composed of different species from Kaizara. *Inoceramus maedae*, n. sp. and its varietal forms from its lower part are much larger than Kaizara forms, and have strikingly inequivalve shells, developed prismatic layers and prominent umbones. The species may remind one of a Cretaceous form. Although the exact age of this fauna should be determined by means of associated ammonites, I am now inclined to consider that it is more or less younger than the Callovian Kaizara fauna. *Inoceramus furukawensis*, n. sp. found by OGASAWARA et al. (1949, MS) from the Sugizaki sandy formation near Furukawa resembles the Makito species. Besides, MAEDA (1957) and MAEDA and TAKENAMI (1958) announced the occurrences of *Inocerami* respectively at Shimohambara of the Upper Kuzuryu and at Arimine area.

Inoceramus morii and *I.* (s. l.) *fukadae* occur in more or less coarse littoral sandstones of the Aratozaki and Kodaijima formations, but they are rather exceptional cases. Most other specimens dealt with in this paper were obtained from fine sandstones or black shales which are characteristically distributed in the Kitakami mountainland and Inner zone of Southwest Japan. In such fine rocks inoceramids are frequently accompanied by ammonites, aptychi, posidoniids and some other thin-shelled pelecypods but scarcely by trigoniids and hexacorals. It is concluded that the inoceramids have been generally fond of somewhat deep, muddy and fairly stagnant condition of inland sea or embayment. In the Outer zone of Southwest Japan and Soma area of Northeast Japan, the Upper Jurassic Torinosu group or its comparable calcareous forma-

Table 1. Distribution of Jurassic Inoceramids in Japan.

Age	West Japan — Toyora area		Central Japan — Kuzuryu and Makito areas			Shizukawa and Hashiura areas		Northeast Japan — Ojika and Kesen areas	
Neocomian	Toyonishi group — Yoshimo fmt.	I. d sp.	represented but no inoceramid			Jusanhama group	no inoceramid	represented but no inoceramid	
Tithonian	Toyora group	?				Sodeno-hama fmt.	I. sp.	Kogoshio fmt.	I. (?) sp.
Kimmeridgian		?				?		?	
Oxfordian		?	Mitarai fmt.	(I. furukawaensis) I. maedae, I. c sp.	I. ? ...	Arato fmt. (Hashiura group)	I. hashiurensis, I. sp. ex gr. galoi	Shishiori group / Tsunaki-zaka fmt.	I. karakawaensis, I. cf. lucifer, I. b sp.
Callovian	Utano fmt.	I. utanoensis, I. ogurai		?				Karakuwa group / Kosaba fmt.	I. morii
Bathonian		no inoceramid	Kaizara fmt.	I. ? naganoensis, I. cf. nitescens, I. hamadae		Aratozaki fmt.	I. morii, P. sp.	Kodaijina fmt.	I. (s.l.) fukadae, I. (s.l.) a sp.
Bajocian	Nishinaka-yama fmt.	I. sp. ex gr. fuscus		?					I. (s.l.) kudoi
Aalenian		P. matsumotoi, P. cf. matsumotoi	represented but no inoceramid			Hosoura fmt. (Shizukawa group)	not represented		
Toarcian		P. lunaris							
Pliensbachian	Higashi-nagano fmt.	not represented	Kuruma group	no inoceramid		Nirano-hama fmt.	no inoceramid		
Sinemurian		no inoceramid							
Hettangian		no inoceramid							

tions, whose fauna is characterized by the abundant stromatoporoids, herma-typic hexacorals, *Cidaris*, *Nerinea* and many neritic or even pelagic pelecypods, are extensively distributed, but no specimen of *Inoceramus* have ever been found. The fact seems to imply something on palaeogeography and palaeo-climatology.

Distribution of Foreign Jurassic Inoceramids

Compared with Cretaceous species, Jurassic inoceramids so far reported in the world are not so numerous (see the synoptic list in this paper), and the distribution is restricted properly to the following four provinces.

1) **Europe—Western Tethys province** (England, France, Germany, Swiss, Italy, Morocco, Czechoslovakia, Poland, Turkey and Caucasus).

In Europe Jurassic inoceramids were described by Schlotheim (1813), Sowerby (1825, 1826), Zieten (1830), Goldfuss (1836), Dunker (1851), Morris and Lycett (1853), Quenstedt (1856), Oppel (1862), Ooster (1869), Dumortier (1874), Blake (1875), Blake and Hudleston (1877), Rollier (1914), Arkell (1933) and some others. Rollier published a list of European species in which he discussed their occurrences and synonimies, but so far as I know, there is no comprehensive revision on this group in recent papers. Since most of European species were established very early, the specific identification of inoceramids in other areas with such European species may be frequently difficult, unless one has a chance examining the type specimens or those species are redescribed with better illustrations on the basis of lectotypes. *Inoceramus pinnaeformis* (Dunker) from the lower Lias is probably the earliest inoceramid in Europe. Upper Liassic and Aalenian small mytiliform species such as *Inoceramus dubius* Sowerby, which were referred by some Russsian authors to *Mytiloides* Brongniart, seem to be well represented, and some of them were reported also from Carpathia by Andrusov (1932), from Anatolia by Stchepinski (1942) and Otkun (1942) and from Caucasus by Pčelinčev (1928, 1933, 1937) and Leontjew (1950). In these areas inoceramids occur in black argillaceous rocks belonging to the Alpine geosynclinal facies. Bajocian species are also very common, and may be represented by orbicular *Inoceramus polyplocus* Roemer and subrhomboidal *Inoceramus fuscus* Quenstedt. Some allied species to the latter are found also in the Great Oolite series. Malm species appear comparatively rare in Europe, but some occur in the lower and upper calcareous grits of the Corallian and in the Kimmeridge clay of England.

2) **Eastern Tethys—Australasia province** (Himalaya, Cutch, Borneo, Timor, Moluccas, New Guinea, New Caledonia and New Zealand).

In this province Upper Jurassic (especially Oxfordian) inoceramids appear fairly common. *Inocerami*, mainly regularly ribbed species such as *Inoceramus everesti*, are important constituents in the fauna of the Spiti shales (Holdhaus, 1913). In Spiti the fossiliferous rocks are limited in a narrow area, but similar shales are extensive in Tibet without any striking facies change. Moluccas

and its surrounding seem an important field for a study of this kind. Since BOEHM (1907) had described several Oxfordian species from Sulu, *Inoceramus galoi* and some other coarse-ribbed species were announced also in Misol and Timor. A comprehensive study of the Upper Jurassic *Inocerami* in this regions was undertaken by WANDEL (1936), who distinguished four species and discussed the classification and synonymy. Upper Jurassic species are also rich in New Caledonia and New Zealand. Since HOCHSTETTER (1863) had erected *Inoceramus haasti*, ZITTEL (1864), TRECHMANN (1923), MÁRWICK (1953), ROUTHIER (1953) and AVIAS (1953) contributed to the palaeontology. According to them, the Upper Jurassic inoceramids of Spiti, Moluccas, New Caledonia and New Zealand are fairly similar to one another in the assemblage of species. In this province Liassic and Dogger species are quite rare. Only two unnamed inoceramids were reported from the Lias of Madagascar and New Caledonia.

3) **Boreal province** (Greenland, Prince Patrick, Alaska, Alberta, Petschola, Yenisei, Franz Joseph Land and the greater part of North Siberia).

KEYSERLING (1848) described *Inoceramus retrorsus** from Siberia, which was later reported also from the Bathonio-Callovian in Jameson Land of East Greenland (SPATH, 1932; DONOVAN, 1953) and lower Lena (LAHUSEN, 1886). VON EICHWALD (1865, 1871) erected 4 species based on the collections from European Russia and Alaska. He described Alaskan forms as "Neocomian or Gault species", but NEUMAYR (1885), MARTIN (1926) and many others are of opinion that they are Jurassic. Among von EICHWALD's species *Inoceramus lucifer* was redescribed from the Bajocian of North Alaska by IMLAY (1955) and Prince Patrick by FREBOLD (1958) as a guide fossil. *Inoceramya* proposed by ULRICH (1910) on the basis of *Posidonia*-like specimens from the Yaktat group of Alaska may imply something on the phylogeny. Besides, McLEARN (1924) and WARREN (1932) described some new species from the Fernie shales of Alberta, but their occurrences appear somewhat sporadical.

4) **Andine province** (Peru, Neuquén, Mendoza and Patagonia).

In the South Andes occur several species from the Lias of Peru and Neuquén (LEANZA, 1942, etc.) and the Tithonian-Neocomian of Patagonia (FERUGLIO, 1936), though the occurrences seem to be somewhat sporadical. According to BEHRENDSEN (1891) and JAWORSKI (1926), some Argentina specimens, though they were not illustrated, are comparable with some species from the European Lias and Moluccan Malm.

Surverying the distribution of foreign and domestic Jurassic inoceramids, it is noticed that they occur more commonly in the shaly or muddy facies than in the sandy or limy facies. A few species such as *Inoceramus fittoni* MORRIS and LYCETT occur exceptionally in calcareous rocks. Striking is the distribution forming two belts in temperate and tropical zones. One is the Alpine-Caucasus geosynclinal region, where Liassic and lower Dogger primitive species occur more or less commonly in Pre-Alps, East Alps, Carpathia, Anatolia and Cauca-

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* Its age was lately discussed by VORONETZ and LAPTINSKAJA (1954).

sus. In the adjacent areas of Western Europe and Northern Africa contempo-
raneous inoceramids are comparatively uncommon, notwithstanding the fact
that other neritic pelecypods are better represented. The other belt is the
Himalaya-Moluccas-New Zealand region where Oxfordian and later regularly
ribbed species are common. The Spiti shales are overlain by the Cretaceous
" Flysch " of the Himalayan geosyncline and bear also geosynclinal characters,
though the thickness is comparatively small. Cutch is a classical Jurassic lo-
cality and considered to have been situated on a stable continental shelf of
Gondwana. Although its Upper Jurassic rocks contain rich ammonites and
neritic pelecypods, inoceramids are unknown but for an indeterminable species
represented only by one specimen (Cox, 1940). A similar fact is also seen in
East Africa or Ethiopian province. The pelecypod faunas of that province are
well characterized by *Eligmus* and *Gryphaea*, being somewhat allied to the To-
rinosu-Soma fauna of Japan. The southeastern part of the belt coincides with
the Papuan geosyncline or the inner margin of Neo-Australia from Moluccas
through New Caledonia to New Zealand where the thickness of Jurassic sedi-
ments approaches 5,000 meters. These two belts roughly form the greatest
mobile zones of the Cretaceous or later ages.

In the boreal region, on the contrary, the distribution of the Jurassic ino-
ceramids does not form such a belt. Sediments are generally not so thick as
in the above two regions. The Fernie shales in West Canada show fairly slow
deposition which took place under off-shore condition in Early Jurassic times
(FREBOLD, 1953; IMLAY, 1957). Middle and Upper Jurassic inoceramids were re-
ported often with arctic ammonites and *Aucella*. But according to IMLAY's
observation in North Alaska (1955), " The absence of almost ubiquitous *Ino-*
ceramus in *Aucella* beds and its rarity even in the same formations suggest that
two genera lived under different environmental conditions, that is, *Aucella* may
have lived in waters that were too agitated or too shallow for *Inoceramus* to
exist ". Though *Aucella* has not been ever found in Japan, the statement seems
to agree to a certain extent with my observation on the Jurassic ecology of
this country. The black shales of the Kitakami mountainland and the Inner
Zone of Southwest Japan are not geosynclinal sediment, but most inoceramids,
as ascertained from many stratigraphical columns, seem to have been fond of
more muddy, stagnant and probably deeper sea bottoms than most other pelecy-
pods. The Japanese Jurassic inoceramid fauna is apparently composed of the
mixture of Tethyan and Arctic elements. For example, some of the species of
the Bajocian to Kimmeridgian Arato formation and its comparable strata are
comparable to *Inoceramus polyplocus* (an European element), *I. galoi* (a Moluc-
can element) and *I. lucifer* (a boreal element). But the greater part of the
available specimens is obviously different from the species hitherto described
in the above mentioned provinces.

Descriptive Terms and Diagnostic Characters

Descriptive terms used by NAGAO and MATSUMOTO (1939–1940) are mostly

applied also to the Jurassic species in this paper. Because most specimen at hand are more or less deformed secondarily owing to the thin tests and fissile mother rocks, I could not put great stress on the biometry. But the dimensions, if many specimens are measurable, are important to clarify the evolution of this family especially Jurassic species. The Lower Jurassic species are always small, scarcely in excess of 5 cm. in maximum length, while the Upper Jurassic species are often as large as the Cretaceous ones. I use the following terms to indicate the size (maximum length of shall); very small, less than 19.5 mm. ; small, 20.0–39.5 mm. ; medium, 40.0–69.5 mm. ; large, 70.0–99.5 mm. ; very large, more than 100.0 mm.
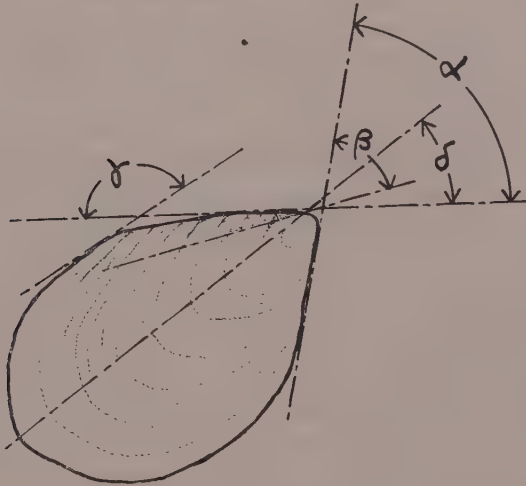
Text-fig. Measurement of angles.

α : Apical angle between hinge and anterior margin.
β : Beak angle of umbonal inflation.
γ : Postero-dorsal angle between hinge and postero-dorsal margin.
δ : Obliquity between hinge and the line from umbo to the most distant point on ventral margin.

The outline is regarded here as the most important criterion for the distinction among species and groups of higher category, although attention must be paid against the secondary deformation and the individual variation. In the Jurassic species the anterior margin is usually not differentiated into antero-dorsal and antero-ventral and very prosocline. The obliquity, which is indicated by the angle between the hinge and the line from the beak to the most distant point on ventral margin (Text-fig.), is generally smaller than in the more advanced species. Posterior wing is absent or undeveloped except for a few species, but the postero-dorsal part is often angulated, flattened or defined clearly from the remaining surface in Jurassic species. The prominence of umbonal region is one of distinctive characters of inoceramids from isognomonids. The umbones of the Jurassic species are, however, generally less prominent than the Cretaceous ones, and its state may be important for the consideration of phylogeny. The apical angle between hinge and anterior margin

(antero-dorsal margin, if differentiated) is comparatively small in the Jurassic species, but the beak angle between the beak inflation exclusive of postero-dorsal area, though it is often immeasurable in accurary, is not always smaller than the more advanced species, because of the less prominent umbones. Inequivalveness is often observed in the Cretaceous inoceramids, especially *Actinoceramus*, *Volviceramus* and many species of *neocomiensis*- and *concentricus*-groups. The careful study on the trend from equivalve to inequivalve (or from inequivalve to equivalve) in each inoceramid group may be important for the phylogeny. The Jurassic species in Japan are always equivalve or subequivalve except for *Inoceramus maedae*, and the major trend of the family appears the morphological transformation from equivalve to inequivalve. The tendency probably suggests a change of habit from vertical to subhorizontal situation against sea floor, and agrees with those of the Bakevelliidae and Isognomonidae. Judging from the absence of byssal gape and the muddy facies, inoceramids probably had not strong byssi.

Most species of inoceramids are edentulous. But the presence of *Bakevellia*-like dentition, i. e. two small cardinal (or anterior) and one or two elongated lateral (or posterior) teeth, seems one of ancestral features of the family. Such a dentition is often observed in the Liassic species. The denticles of *Parainoceramus matsumotoi*, n. sp. and more other related forms remind at a glance one of mytilid's hingement; that is, the cardinals resemble *Mytilus*' umbonal teeth and laterals a tooth-like ridge for adherence of a ligament running subparallel to the dorsal margin in most species of the Mytilidae. But such umbonal teeth do not appear in the Jurassic or earlier species of the Mytilidae, and the posterior teeth are frequently two in number in the present specimens. The similarity can be regarded as superficial.

Numerous pits arranged along a narrow ligament area are fairly characteristic of inoceramids. As stated by Cox (1940, p. 125), Heinz's distinction between *Inoceramus* and *Isognomon* on the basis of ligament structure may be not always applicable, but the ligament pits of inoceramids are generally less elongated vertically and more numerous than contemporaneous isognomonid. Though some Recent species of *Isognomon* have comparatively thin tests, Mesozoic species of the genus have usually much thicker shells (lamellar layer) than *Inoceramus*. The ligament characters in primitive inoceramids seem especially important to solve the phylogeny, but the area of small forms is tolerably narrow and often difficult to examine in detail. Musculature is an important criterion for pelecypod classification, but it has been scarcely observed in *Inoceramus*.

The shell structure of inoceramids is famous for the developed prismatic calcite layer. The character may be also essential for the classification, but it is fairly difficult at present to apply the shell structure to the subdivision of the family, since investigators are required to consider carefully the different state of preservation, size and maturity among individuals and also the orientation of thin sections. In the greater part of the present material, the shells are exfoliated, eroded out or displaced by other material than carbonates, and

some forms are represented only by "Steinkern". The microscopic observation could be carried out only on two species, *Inoceramus morii* and *I. maedae*. The prismatic layer of *morii* is very thin and composed of minute crystals, while the calcite prisms of *maedae* are fairly large, elongated and comparable in the dimensions with those of some Upper Cretaceous species.

Ornamentation is regarded as one of the diagnostic criteria for the classification of Cretaceous *Inocerami*. But non-concentric (oblique, divergent or radial) sculptures scarcely appear in the Jurassic species. In *Parainoceramus* and the primitive groups of *Inoceramus*, prominent concentric lamellae, if present, are somewhat irregular and sometimes difficult to be demarcated from growth-lines. However, in some large Upper Jurassic species (ex. *I. galoi*) concentric sculpture is fairly regular and distinctly plicated. Strong constrictions are sometimes observable in the Middle and Upper Jurassic species (ex. *I. lucifer*).

Provisional Classification of Jurassic Inoceramids

No comprehensive study on the classification of Jurassic inoceramids has as yet been published. *Inoceramus* (sensu lato) is in fact a large but difficult group to classify. As to Cretaceous species attempts have been done to separate them into several groups or genera by MEEK (1864), STOLICZKA (1871), WOODS (1911, 1911–1912), BOEHM (1915), NAGAO and MATSUMOTO (1939–1940) and others, and the phylogenetical development of the family is partly clarified. But diverge opinions were expressed as to the taxonomy and nomenclature. Many authors consider that Jurassic and Cretaceous species belong to one genus, *Inoceramus*, but HEINZ (1932, etc.) showed his scope of "Neue Systematik" and splitted Cretaceous species into 63 genera and 28 subgenera in 2 families and 24 subfamilies as the result of his observation on the surface ornamentation and other characters. However, each category in his mind seems evidently out of proportion to other lamellibranch genera and families, and the diagnostic characters of the groups are not always clear. His classification has been repeatedly criticised by COX (1940, 1954), ARKELL and MOY-THOMAS (1941) and some others. Since the phylogeny of Jurassic and Early Cretaceous inoceramids has not been sufficiently clarified to make a natural classification, their separation into many genera is inevitably apt to become artificial.

Putting aside HEINZ's classification, the following names were proposed for various groups of the Inoceramidae on the basis of the deviated morphological characters from typical *Inoceramus* SOWERBY, 1814.

Mytiloides BRONGNIART, 1822
Anopaea VON EICHWALD, 1861
Actinoceramus MEEK, 1871
Volviceramus STOLICZKA, 1871
Cucullifera CONRAD, 1875
Haploscapha CONRAD, 1875
Endocostea WHITFIELD, 1885
Neocatillus FISCHER, 1887
Neoinoceramus IHERING, 1903

Inoceramya Ulrich, 1910
Mytiloceramus Rollier, 1914
Sphenoceramus Boehm, 1915
Haenleinia Boehm, 1915
Sergipia Maury, 1925
Parainoceramus Voronetz, 1936

These groups except for *Inoceramya*, *Mytiloceramus* and *Parainoceramus* are founded on somewhat specialized Cretaceous species. But before they are accepted as generic or subgeneric names, one must examine carefully their type-species. Woods (1911, 1911–1912), who carefully studied the phylogeny of the Cretaceous inoceramids of England, did not recognize the type-species of *Mytiloides*, *Actinoceramus* and *Volviceramus* as subgenerically distinct from *Inoceramus*, since they are allied to typical species of *Inoceramus*. Since I am not in a position to examine the type-species of these Cretaceous groups, I do not intend here to evaluate their validities, but apply the group-names proposed by Woods (1911) and Nagao and Matsumoto (1939–1940).

Most Jurassic inoceramids, on the contrary, have been referred to *Inoceramus*. Jurassic species seem, however, to be generally distinguished from Cretaceous ones by many primitive or less specialized features such as the undeveloped prismatic layers, equivalve or subequivalve shells, less prominent umbones, prosocline outlines and absence of radial plications. Pčelinčev (1937) and some Russian authors assigned *Inoceramus dubius* Sowerby, *I. amygdaloides* (Schlotheim), *I. cinctus* Goldfuss, *I. gryphoides* (Schlotheim) and *I. quenstedti* Pčeninčev from the Lias and Aalenian of Europe, Asia Minor, Caucasus, Western Siberia and Madagascar to *Mytiloides* Brongniart, 1822. *Mytiloides* was, however, founded on *Ostracites labiatus* Schlotheim, 1813 (by monotypy), a well-known Upper Cretaceous species, and its essential characters, if the obliquely elongated outline is ignored as a specific character, are seemingly not so deviated from those of typical *Inoceramus* that no generic distinction is required for the species. As stated by Woods (1911–1912) the species may not be much apart from some varietal forms of *Inoceramus crippsi*. Such small Liassic and Aalenian species are, I think, anyhow different from the type-species of *Inoceramus* and *Mytiloides* at generic level. On the other hand Voronetz (1936) proposed *Parainoceramus* from the Upper Triassic of North Siberia. Kiparisova (1938) did not recognize *Parainoceramus* as a distinct genus, and assigned it congeneric with "*Mytiloides*" in her mind. Recently Cox (1954, p. 47), however, selected its type-species and included *Crenatula ventricosa* Sowerby and *Inoceramus substriatus* Münster in Goldfuss from the Lias of Europe in the genus. The generic characters were more or less clearly expressed by him. So far as I can judge from foreign literatures and a few European specimens kept in this institute, most other Liassic small species are considered to belong to *Parainoceramus*. Several species belonging to the genus are found also in the middle and upper Lias of Japan, Neuquén and (?) New Caledonia. It is certain that such primitive inoceramids have flourished universally in Early Jurassic times prior to large species. *Parainoceramus* is generally characterized by the small

size (rarely exceeding 5 cm. in maximum length), mytiliform prosocline outline, comparatively improminent umbonal area, weak concentric ornamentation thin prismatic layer and sometimes posessing a small anterior wing and weak cardinal and lateral teeth.

Generic distinction of Dogger and Malm inoceramids from typical Cretaceous *Inoceramus* seems difficult, because of the absence of any striking distinctive characters. ROLLIER (1914) proposed *Mytiloceramus* for *Inoceramus polyplocus* ROEMER from the Bajocian. According to GOLDFUSS (1836), BENECKE (1905) and SCHMIDTILL (1926) the species shows a somewhat *Posidonia*-like orbicular outline, and may form a distinct group, probably a subgenus of *Inoceramus*, since most other Dogger and Malm species have mytiliform or subrhomboidal shells with very prosocline anterior margins. Mytiliform (or subrhomboidal) large inoceramids appeared in Aalenian-Bajocian in many areas of the world, and flourished until Callovian-Oxfordian. *Inoceramus lucifer* VON EICHWALD having inflated shells and strong surface constrictions appear in the Bajocian of the Arctic region (group of *I. lucifer*). The group may be phylogenetically connected with *Inoceramus propinquus* MÜNSTER in GOLDFUSS, 1836, from the Lower Cretaceous. In Europe *Inoceramus fuscus* QUENSTEDT and some other related species, which have rhomboidal outline and comparatively weak ornamentation, occur in Dogger (group of *I. fuscus*), and a few species of this group are found also until Oxfordian. The group is at a glance similar to *Parainoceramus* from the Lias, but generically separable by the larger dimensions, more prominent umbo and absence of anterior wing and hinge-teeth. Certain species such as *Inoceramus quenstedti* PČELINČEV and *I. falgeri* MERIAN seem intermediate between the two groups, but it may suggest at the same time that at least a part of Jurassic subrhomboidal *Inoceramus* was derived from *Parainoceramus*. Coarse-ribbed large inoceramids flourished chiefly in the Callovian and later stages of Himalaya, Moluccas–New Zealand (group of *I. galoi*). This group shows variable outlines from mytiliform to subtrapezoidal, and may have been connected with some Cretaceous *Inocerami*. Some arctic species such as *Inoceramus retrorsus* KEYSERLING show irregular ribbing and more or less developed posterior wing (group of *I. retrorsus*). *Inoceramus utanoensis* and *I. ogurai* from the upper Toyora group in West Japan may belong to the group. All the above groups are characterized by the equivalve shells, and the antero-dorsal and antero-ventral margins are not clearly differentiated. A strikingly inequivalve inoceramid was, however, found in the Upper Jurassic of Japan. Judging from the ornamentation, large obliquity of shell and prominent umbones, the species is fairly different from the hitherto reported Jurassic ones and seems to be connected with the group of *I. neocomiensis* from the Lower Cretaceous.

Although there are some intermediate species between the two groups and several aberrant forms, my provisional classification of Japanese Jurassic inoceramids can be summerized as follows:

Parainoceramus ....Late Triassic—Bajocian

Group of *I. polyplocus* (Subgenus *Mytiloceramus*) ....
....Aalenian—Bathonian

Group of *I. fuscus* ....Toarcian—Oxfordian

Inoceramus   Group of *I. lucifer* ....Bajocian

Group of *I. retrorsus* ....Bathonian—Oxfordian

Group of *I. galoi* ....Callovian—? Cretaceons

Group of *I. neocomiensis* ....? Oxfordian—Albian
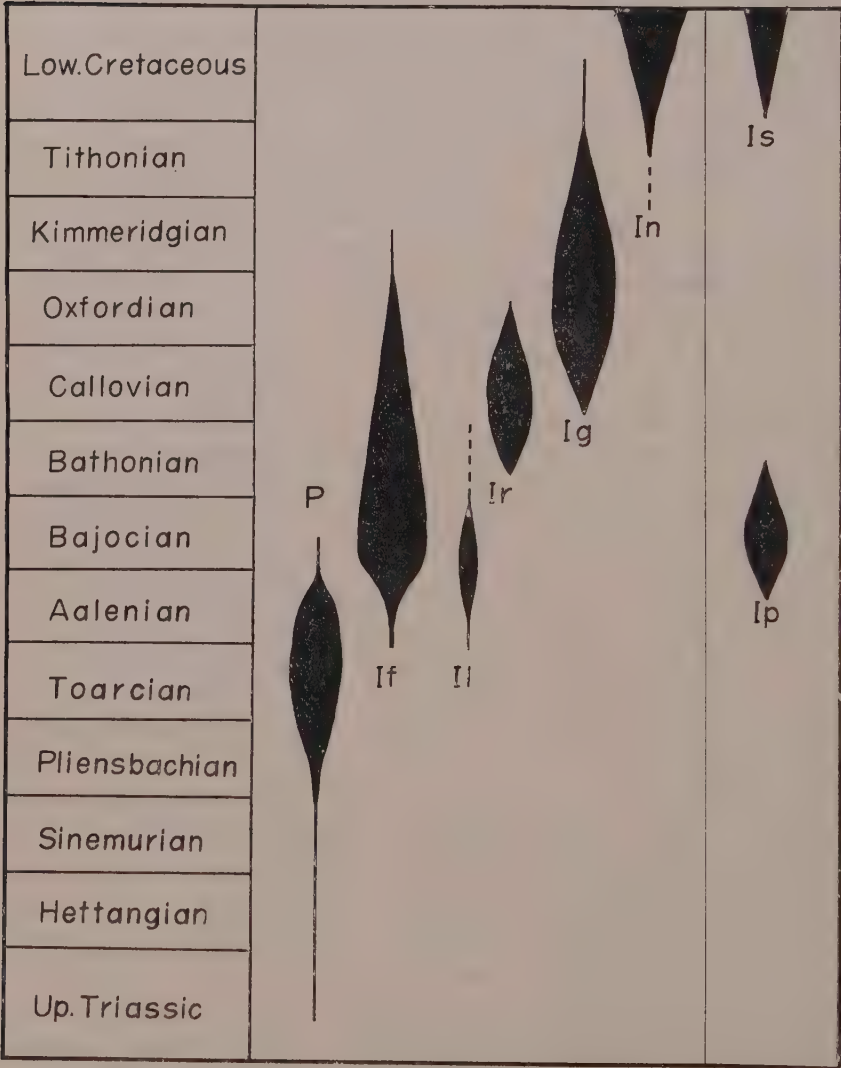
Text-figure 1. Stratigraphical Distribution of Jurassic Inoceramids.

P : *Parainoceramus*;   If : Group of *Inoceramus fuscus*;   Il: Group of *I. lucifer*;
Ir : Group of *I. retrorsus*;   Ig : Group of *I. galoi*;   In : Group of *I. neocomiensis*:   Ip : Group of *I. polyplocus* (subgenus *Mytiloceramus*);   Is : Group of *I. salomoni*.

Phylogeny

The ancestry of the Inoceramidae has not been clarified. It is possible to consider that Dogger and later *Inocerami* at least in part are originated from Liassic *Parainoceramus*, but if one traces the stock into the Triassic, the phylogeny becomes much obscure. Only several species of *Parainoceramus* described by VORONETZ (1936) from the "Upper Triassic"* of North Siberia are referable to the family with a certain confidence. As stated by many authors, *Inoceramus* is sometimes akin to *Isognomon* in Jurassic times. The prismatic layer is still undeveloped and the umbo is generally less prominent than Cretaceous species. Therefore, the Inoceramidae, if not all groups, are regarded as allied to the Isognomonidae: both families may have been derived from similar stocks.

Multivincular pelecypods appeared in the Permian, represented by *Bakevellia* KING, 1848, which is generally considered as the main trunk of the Bakevelliidae and is persistent until Cretaceous. Since *Isognomon* has not been known in the Palaeozoic and Lower Triassic, I (1957b) suggested that the Isognomonidae may have been derived from the Bakevelliidae. However, a newly collected specimen from the *Parafusulina matsubaishi* bed of the Kanokura group (Middle Permian of North Japan shows similar characters to Jurassic and later *Isognomon* (s. s.), i. e. fairly large dimensions, five or more ligament pits, linguiform outline, more or less gaped and sinuated anterior margin, as described in the supplement of this paper. The ligament area is elongated along the hinge-line and not trigonal as in early representatives of *Bakevellia*. The anteriorly projected umbo, weak inflation and presence of an elongated tooth on the interior of posterior area may remind one of *Cuneigervillia* COX, 1954, from the Lias. But it is plausible to consider that *Isognomon* or its allied pelecypods appeared already in the Middle Permian and since then form an independent trunk of the Isognomonidae from that of the Bakevelliidae.

COX (1940, p. 126) and some other authors suggested the possibility that two or more stocks of independent origin may exist in the Jurassic inoceramids. Other candidates for the ancestors of the Inoceramidae are the Posidoniidae and Myalinidae. GUILLAUME (1928) stated that multivincular ligament structure exists in *Posidonia bronni* VOLTZ in ZIETEN, 1930, from the Toarcian for which FISCHER (1887) proposed *Steinmannia*. But the exterior of that species is of typical *Posidonia*, and *Inoceramus*-like appearance cannot be felt. On the other hand ULRICH (1910) described *Inoceramya concentrica* as a new genus and new species from the Yaktat group, undated "Mesozoic" formations on the Pacific coast of Alaska. He assumed the genus to be transitional between *Posidonia* ane *Inoceramus*, suggesting that it is an ancestral form of inoceramids. In fact, its multivincular ligament structure and regular concentric ornamentation resemble those of *Inoceramus* especially the group of *I. polyplocus*. But in the

* VORONETZ noted that *Parainoceramus* was accompanied by *Trigonodus* and an ammonite with a ceratitic suture, though similar inoceramids of other areas occur always from the Lias or Bajocian.

Alaskan species the umbo is not subterminal and the preumbonal margin is fairly long and almost horizontal, and the external features are more similar to *Posidonia* than *Inoceramus*. *Posidonia revelata* KEYSERLING, 1846, from the Jurassic of Petchola shows also large dimensions for Mesozoic *Posidonia*, multivincular pits of inoceramid-type (fig. 12) and *polyplocus*-like outline (fig. 13). I am now inclined to consider that some species of *Inoceramus* may have originated in the Posidoniidae, but its greater part may have been derived from the Isognomonidae through *Parainoceramus* or some primitive inoceramids such as *fuscus*-group. Myalinids are probably not directly ancertral to inoceramids, but it is possible that isognomonids are descendants from the Myalinidae instead of the Bakevelliidae or *Pteria*-like families.

It is concluded that the development of the Inoceramidae is roughly divided into four steps. The first period is the stages from the Upper Triassic to upper Lias when *Parainoceramus*, showing small size, dentitions and other primitive features, is well represented. Large inoceramids, if present, are very rare in this period. The second period from the lower Dogger to lower Malm or thereabout is characterized by the differentiation and somewhat rapid transformation. Many groups of *Inoceramus* appeared in early Dogger times. Bajocian species are especially common. If *Posidonia*-like *polyplocus*-group is ignored, most inoceramids in this period were probably derived from *Parainoceramus*. The *fuscus*-group includes many species and is regarded as a main trunk of the Inoceramidae. Near the end of this period the *galoi*-group and the *retrorsus*-group appeared respectively in the Australasia and boreal provinces. *Inoceramus* is relatively uncommon in the third period from the upper Malm through Neocomian to Albian, but the period is characterized by the first appearance of inequivalve and polygonal species. The *neocomiensis*-group and *salomoni*-group constitute the main trunks in this period (WOODS, 1911; GILLET, 1924). The fourth period is the rest of the Cretaceous (from Albian up to Maestrichtian) when the development of the family attained the climax. There are many aberrant and specialized inoceramids for which many generic and subgeneric names were hitherto proposed.

Description of Jurassic Inoceramids in Japan

Family **Inoceramidae** ZITTEL

Genus *Parainoceramus* VORONETZ, 1936

Type-species:—*Parainoceramus bulkurensis* VORONETZ, 1936, Upper Triassic, North Siberia (by Cox, 1954).

Diagnosis:—Shell equivalve, of moderate convexity, rectangular or rhomboidal, sometimes posteriorly subalate; umbones not inflated, level with or not rising much above hinge-margin; beaks subterminal; no byssal gape; anterior surface of shell more or less impressed; ligament area flat, pits numerous; surface smooth or with weak concentric folds; prismatic layer thin except along hinge-line. (according to Cox, 1954)

Remarks :—Besides *bulkurensis* and three other Siberian species by VORONETZ (1936), this genus seems to include the greater part of Liassic small species from Western Europe, Alps, Carpathia, Anatolia, Caucasus, Siberia, Neuquén and New Caledonia as follows:

Inoceramus amygdaloides GOLDFUSS, 1836
Inoceramus apollo LEANZA, 1942
Inoceramus cinctus GOLDFUSS, 1836
Inoceramus depressus MÜNSTER in GOLDFUSS, 1836
Inoceramus dubius SOWERBY, 1826
Mytilus gryphoides SCHLOTHEIM, 1813
Inoceramus pernoides GOLDFUSS, 1836
Gervillia pinnaeformis DUNKER, 1851
Inoceramus substriatus MÜNSTER in GOLDFUSS, 1836
Perna thermarum MOESCH, 1867
Crenatula ventricosa SOWERBY, 1825
Inoceramus (?) sp. in AVIAS, 1953

Faint radial striations were drawn in the original figures of *substriatus*, *pernoides* and *ventricosa*, and also are seen on the surface of a specimen of " *I. dubius* " preserved in this institute (M 288). But they are very weak and tolerably different from the broad plications of Cretaceous species. In Japan five forms of *Parainoceramus* are found in the Domerio-Toarcian Nishinakayama and Bajocian Aratozaki formations, They have frequently weak cardinal and posterior lateral teeth of *Bakevellia*-type which have been reported also in young individuals of *Isognomon* and *Cuneigervillia*. COX (1954) stated the presence of two internal tooth-like ridges in the angle of the rudimentary anterior wing of *substriatus*, and such a feature is regarded as a primitive character in early representatives of the Inoceramidae.

Parainoceramus lunaris HAYAMI, new species

Plate XV, Figure 1.

Description :—Shell very small to small, equivalve, inequilateral, gibbose to linguiform, probably not strongly inflated, much higher than long ; hinge-line fairly long, occupying about two-thirds of shell-length ; anterior margin long, straight or even slightly concave, prosocline, meeting hinge-line with an apical angle of about 85 degrees ; posterior and ventral margins gently arcuate ; anterior wing small ; beak angle not measurable owing to ill-defined postero-dorsal area ; postero-dorsal corner much rounded, not forming posterior wing ; umbo subterminal, improminent ; two strong subhorizontal cardinal teeth present at anterodorsal angle ; lateral teeth two in number, elongated, subhorizontal or slightly oblique to hinge-line ; surface smooth except for many irregular concentric lamellae and numerous faint growth-lines.

Measurement in mm.	Lenght	Height	Thickness	Obliquity
Holotype (MM 3582) right in. mould	15. 5	19. 0	2. 5	70°
Paratype (MM 3583) left valve	16. 0	18. 0	2. 0	75°

Observation and comparison:—Represented by three flattened specimens. The *Bakevellia*-like dentition is clearly seen on the internal surface of the holotype. Although the ligament structure is unknown, this is referable to *Parainoceramus* by the similarity of other essential characters to the next species, *P. matsumotoi*. In the outline *Parainoceramus bulkurensis* VORONETZ, the type of the genus, resembles this species, but the absence of posterior wing and presence of strong lateral teeth prevent me from comparing it to the Siberian species.

Occurrence:—Rare in the *Fontanelliceras* bed (Ne zone in ARKELL, 1956, p. 420) of Nishinakayama formation at Sakuraguchi, southwest of Ishimachi, Toyoda town, Toyora County, Yamaguchi Prefecture. Upper Pliensbachian. This species is usually accompanied by small ammonites, aptychi and an aulacomyellid (*Amonotis* ?) in highly fissile shales.

Parainoceramus matsumotoi HAYAMI, new species

Plate XV, Figures 2–8.

Description:—Shell very small to small, equivalve, inequilateral, submytiliform, to linguiform, slightly broadened downwards, more or less higher than long, not strongly inflated; test thin; anterior wing very small, not clearly demarcated from main body; posterior area not alate but somewhat depressed; hinge-line moderate in length, occupying about a half of shell; anterior margin nearly straight, not gaped, not differentiated into antero-dorsal and antero-ventral, forming an apical of about 70 degrees with hinge-line, passing gradually into ventral margin; posterior margin sligety convex, truncated, forming a postero-dorsal angle of about 130 degrees; umbo subterminal, improminent, rising scarcely above hinge-margin; hinge composed of one or two small granular cardinal teeth and an elongated posterior tooth of *Bakevellia*-type in each valve; cardinals seen only in small specimens and probably obsolete in adult; lateral tooth never disappears but becomes gradually more oblique to hinge-line; ligament area very narrow, nearly flat, provided with numerous pits surface marked with irregularly spaced concentric folds and numerous growth-lines.

Measurement in mm.	Length	Height	Thickness	Obliquity
Holotype (MM 3584) left in. mould	7. 0	8. 0	1. 5	65°
Paratype (MM 3585) left in. mould ˙	19. 5	25. 5	4. 0	65°
Paratype (MM 3586) right in. mould	8. 5	9. 5	1. 5	60°
Paratype (MM 3587) right ex. mould	8. 0	9. 0	1. 0+	65°

Observation and comparison:—Nine specimens are at hand. Though the outline varies to a certain extent, they belong to one species, since the variation is continuous. A small anterior wing is observed in most specimens. The holotype specimen composed of small left external and internal moulds has numeous ligament pits, two weak oblique minute cardinal teeth and an elongated posterior lateral tooth. Such a lateral tooth is observable also in other specimens but the cardinals are not always double and apparently obscure in adult

individuals. The lateral tooth is subhorizontal in small specimens but fairly oblique to the hinge-line in large ones. The tendency agrees with my observation (1957) on *Bakevellia trigona* (YOKOYAMA). This is similar to *Parainoceramus lunaris* in many respects, but differs in the weaker and smaller cardinal teeth, a solitary and less elongated lateral tooth, narrower shell, smaller apical angle, shorter hinge-line and more angulated postero-dorsal corner. This is readily distinguishable from *Parainoceramus bulkurensis* VORONETZ and *P. nikolaiewi* VORONETZ, 1936, from the Upper Triassic of Siberia by the absence of posterior wing (or more rounded postero-dorsal angle) and slightly more elongated outline. Some specimens resemble *Inoceramus* (*Mytiloides*) *amydaloides* GOLDFUSS in PČELINČEV, 1937, from the Toarcian of Caucasus. But GOLDFUSS' original figure of that species (1836) has more horizontally elongated outline (smaller obliquity) and more rounded anterior margin than PČELINČEV's and my specimens. *Inoceramus quenstedti* PČELINČEV, 1933, from the Aalenian of Caucasus, Germany and ? Madagascar is also similar to this in outline, but the dimenfions of *quenstedti* are somewhat larger, suggesting that species is transitional between *Parainoceramus* and the group of *I. fuscus*. Such hinge-teeth as seen in *matsumotoi* are unknown in PČELINČEV's.

Occurrence:—Common in the *Dactylioceras-Hildoceras* bed (Nd zone in ARKELL, 1956, p. 420) of Nishinakayama formation at Ishimachi, Toyoda town, Toyora County, Yamaguch Prefecture. Toarcian. Most of the materials collected by YOKOYAMA and TORIYAMA. MATSUMOTO's collection of the inoceramids from this horizon kept in the Kyushu University may belong also to this species.

Parainoceramus cf. *matsumotoi* HAYAMI

Plate XV, Figure 9.

Description:—Shell very small, equivalve, mytiliform, not strongly inflated, nearly as long as high, not auriculate; hinge-line moderate in length, passing gradually into posterior without any angulations; anterior margin nearly straight, forming an apical angle of about 55 degrees; posterior margin subparallel to anterior but gradually bent down into ventral; umbo subterminal, improminent, not rising above hinge; a weak subhorizontal lateral tooth present in left valve; surface marked with irregular concentric folds.

Measurement in mm.	Length	Height	Thickness	Obliquity
(MM 3591) left in. mould	8. 0	6. 5	1. 0	45°
(MM 3592) right in. mould	8. 5	7. 5	1. 0	50°

Observation and comparison:—Represented by two specimens. Although it is not improbable that this form is actually conspecific with *matsumotoi* from the same fossil bed in view of the similar surface-markings and dentition, the outline is more mytiliform with much smaller obliquity and a more rounded postero-dorsal angle. This is somewhat similar to *Inoceramus dubius* SOWERBY, 1826, from the upper Lias. Because SOWERBY's type illustration is somewhat

obscure, many authors' references of small inoceramids to *dubius* are now con-
fused and cumbersome. Goldfuss's figure (1836, pl. 109, fig. 1) is more clearly
drawn, but Roemer, 1857, established *Inoceramus polyplocus* on it. In compari-
son with Dumortier's figures (1874, pl. 42, figs. 5, 6), this has weaker convexity
and a straight and more prosocline anterior margin which is not differentiated
into antero-dorsal and antero-ventral. *Inoceramus amygdaloides* Goldfuss shows
also smaller obliquity but differs from this in the more elongated outline and
stronger curvature of the anterior margin.

Occurrence:—The same as *P. matsumotoi*. Toarcian. Toriyama coll.

Parainoceramus sp. ex gr. *matsumotoi* Hayami

Plate XV, Figure 10.

An internal mould of a small left valve closely resembles *matsumotoi* in
outline but different in the stronger convexity and more prominent umbo. Two
granular cardinals at the antero-dorsal angle suggest that it is intimate to
matsumotoi, though the posterior lateral is much weaker. The difference of
shell-convexity may be attributed to the different state of preservation, con-
sidering that the matrix of this specimen is more massive. This is at a glance
similar to *Inoceramus morii* Hayami, 1959a, from the Bajocian Aratozaki forma-
tion of Northeast Japan, but differs in the presence of the weak cardinal and
lateral teeth of *Bakevellia*-type, less prominent umbonal area and less steep
anterior slope. Specimen, MM 3593, 12.5 mm. long, 15.0 mm. high, 5.0 mm. thick.
Obliquity ca. 60 degrees.

Occurrence:—Rare in Nd (?) zone at Yasudadani, Nishinakayama, Toyoda
town, Toyora County, Yamaguchi Prefecture. Toarcian. Toriyama coll.

Parainoceramus sp. indet.

1959. *Inoceramus* (?) sp. indet., Hayami, *Japan. Jour. Geol. Geogr.*, *Vol. 30*, p. 60, pl. 5,
       fig. 15.

I intend here to included the *Isognomon*-like small indeterminable species
from the Bajocian Aratozaki formation in *Parainoceramus* on the basis of a
distinct posterior lateral tooth, improminent umbo and the similar outline to
Parainoceramus lunaris. But the shell is more broadly inflated and lateral tooth
much weaker than *lunaris*.

Genus *Inoceramus* Sowerby, 1814

Type-species:—*Inoceramus cuvieri* Sowerby, 1814, Cretaceous, England (defined
by Cox's lectotype designation). The decision of the International Commission
on Zoological Nomenclature related to genus *Inoceramus* and its type species
was published as Opinion 473 in 1957, in response to Cox's application (1955).

Remarks:—Other Jurassic inoceramids than *Parainoceramus* are here referred

to *Inoceramus*. In Japan tne groups of *I. polyplocus, fuscus, lucifer, retrorsus, galoi* and *neocomiensis* are represented by one or a few species in each. Besides, several aberrant forms may belong to the other groups.

Group of *Inoceramus polyplocus* ROEMER

(Subgenus *Mytiloceramus* ROLLIER, 1914)

Diagnosis:—Shell medium to large, suborbicular, equivalve, not strongly inflated; umbo subterminal, not very prominent; a small anterior wing-like area usually present; anterior margin nearly acline, broadly arcuate; apical angle generally larger than contemporaneous inoceramids; surface marked with fairly regular concentric plications which sometimes die out in flattened postero-dorsal area.

Remarks:—This group seems to be restricted to the Dogger (mainly Bajocian) and distinguishable from other groups by the suborbicular outline, subvertical anterior margin and regular concentrics on the surface. As noted before, it is not improbable that this group was derived from *Posidonia*-like pelecypods and has a different origin from other inoceramid groups. ROLLIER (1914) proposed *Mytiloceramus* for *I. polyplocus*, though the outline of the species is rather orbicular than mytiliform, and it is accepted here as a subgeneric name of *Inoceramus*.

Inoceramus (Mytiloceramus) karakuwensis HAYAMI, new species

Plate XV, Figure 17.

Description:—Only right valve known. Shell medium to large, probably suborbicular, not strongly inflated, hinge-line occupying about a half of shell-length; anterior margin subvertical, gently arcuate; apical angle not accurately measured but about 85 degrees or slightly more; posterior margin truncated with an angle of 140 degrees or less; umbo subterminal, risihg slightly above hinge; small anterior wing-like area present; beak angle about 70 degrees; a distinct post-umbonal sulcus defining flattened postero-dorsal area; surface marked with somewhat irregular concentric plications which are much weakened towards umbonal and postero-dorsal areas; hinge apparently edentulous; ligament structure unknown.

Measurement in mm.	Length	Height	Thickness	Obliquity
Holotype (MM 3597) right in. mould	76. 0	68. 5	9. 5	55°
Paratype (MM 3598) right ex. mould	48. 5	33. 0	5. 5	50°

Observation and comparison:—Represented by two specimens which show subtrapezoidal outline. However, seeing that they are compressed secondarily in antero-ventral to postero-dorsal direction, their original outline must be more orbicular. The post-umbonal sulcus and concentric ornaments in part may be somewhat emphasized in the holotype specimen. This species may be allied

to *Inoceramus polyplocus* ROEMER, 1857, from the Bajocian of Europe (BENECKE, 1905 ; SCHMIDTILL, 1926) in the imaginable original outline. Because of the strong deformation of the present material, a detailed comparison of outline seems difficult, but the dimensions are larger and the postero-dorsal area of this species is probably more flattened, better defined and more weakly sculptured than *polyplocus*. The scuptures on the remaining part are apparently coarser, stronger and more irregular.

*Occurrence :—*Rare in black shales of Tsunakizaka formation (ONUKI, 1956) at the southeast of Tsunakizaka-pass, Shishiori, Kesennuma City, Miyagi Prefecture. SATO (1956) reported *Stephanoceras* sp. ex gr. *plicatissimum* QUENSTEDT from its adjacent horizon. Middle Bajocian or thereabout. YAMASHITA coll.

Group of *Inoceramus fuscus* QUENSTEDT

*Diagnosis :—*Shell small to medium for genus, equivalve, subrhomboidal and sometimes obliquely elongated, moderately or fairly strongly inflated ; both wing absent or undeveloped ; postero-dorsal area not flattened, illdefined from remaining part ; anterior margin straight, prosocline, not differentiated into antero-dorsal and antero-ventral ; posterior margin usually straight, subparallel to anterior ; umbo terminal, sometimes fairly prominent ; hinge edentulous ; prismatic layer usually thin ; surface marked with many irregular concentric lamellae which are comparatively weak and not clearly distinguishable from growth-lines.

*Remarks :—*The group of *Inoceramus fuscus* in my classification is composed of *I. fuscus* and many other subrhomboidal species and regarded as the main trunk of the Inoceramidae during Middle Jurassic and lower Upper Jurassic. Sometimes this group shows similar outline to *Parainoceramus*, but readily distinguished from the genus by the much larger dimensions, absence of hinge-teeth and wings, more prominent umbo and less mytiloid aspect.

Inoceramus morii HAYAMI

Plate XV, Figures 11–12.

1959. *Inoceramus* (s. l.) *morii* HAYAMI, *Japan. Jour. Geol. Geogr., Vol. 30*, p. 59, pl. 5, figs. 12–14.

After the original description of this species had been published, several specimens were further amplified from the Bajocian Aratozaki and Kosaba formations. As I referred then this species provisionally to *Inoceramus* (s. l.), it is not a typical *Inoceramus* and seems to belong to the group of *I. fuscus* QUEN-STEDT, 1856, from the Bajocian of Europe, especially Alpine form of the species described by OOSTER (1869). But if compared with QUENSTEDT's original figure (1856, pl. 48, fig. 18), the surface concentric lamellae seem stronger and the outline is somewhat different. OOSTER and SCHMIDTILL's specimens of *fuscus* may have larger size and weaker inflation than this species. *Inoceramus quenstedti*

PčELINČEV resembles this in the dimensions and surface markings, but the convexity is probably weaker and the umbo less prominent.   It is also similar to *Inoceramus dubius* in DUMORTIER (1874, pl. 42, figs. 5, 6) from the upper Lias of Rhône basin, but the anterior margin is nearly straight and more prosocline. In the several transverse thin sections prepared from the Aratozaki specimens, it was known that the prismatic layer is quite thin and undeveloped.   The prisms are much smaller than those of *I. maedae* from the Malm and normal Cretaceous species.

Occurrence:—Common in the *Trigonia sumiyagura* bed of the lower Aratozaki formation at Akaiwazaki, southwest of Hosoura, Shizukawa town, Motoyoshi County, Miyagi Prefecture, and rare in the basal sandstone of the Kosaba formation at Shibitachi, Karakuwa town, the same county.   SATO (1954a, b) described *Hammatoceras* and *Tmetoceras* from the underlying Hosoura formation, and BANDO (1959) *Cadomites* from the overlying Arato formation.   Bajocian.

Inoceramus sp. ex gr. *fuscus* QUENSTEDT

Plate XV, Figure 13.

ex gr.

1856. *Inoceramus fuscus* QUENSTEDT, Der Jura, p. 355, pl. 48, fig. 18.

? 1867. *Inoceramus fuscus* LAUBE, Bivalv. Braun. Jura Balin, p. 26, pl. 2, fig. 1 (=*Inoceramus balinensis* ROLLIER, 1914).

1869. *Inoceramus fuscus* OOSTER, Jura. Inoceramen Alpen, p. 38, pl. 13, figs. 1–6.

? 1874. *Inoceramus fuscus* DUMORTIER, Études pal. Depôt jura. Bassin Rhône, Vol. 4, p. 307, pl. 61, figs. 6, 7 (=*Inoceramus dumortieri* ROLLIER, 1914).

1926. *Inoceramus fuscus* SCHMIDTILL., *Palaeontogr.*, *Vol. 68*, p. 17, pl. 3, fig. 3.

1950. *Inoceramus fuscus* WETZEL, *Ibid.*, *Vol. 99, Abt. A*, p. 108.

Description of Japanese specimens:—Shell small to medium, equivalve, subrhomboidal, obliquely elongated, not strongly inflated, more or less higher than long (MM 9087, right ex. mould, 35.5 mm. long ; 38.5+mm. high ; 3.5+mm. thick ; obliquity ca. 55 degrees) ; anterior and posterior margins subparallel to each other, prosocline, forming respectively an apical angle of about 65 degrees and postero-dorsal angle of about 115 degrees with hinge-line ; both wings absent ; postero-dorsal area ill-defined ; surface marked with about 15 irregular concentric foldings and numerous growth-lamellae.

Observation and comparison:—Four external moulds adhered to a slab of black shale.   They must be compressed secondarily, because their valve-margins are subparallel to the bedding plane.   Although the hinge and original shell-convexity are unknown, this form seems to be closely allied to *Inoceramus fuscus* QUENSTEDT from the Bajocian of Europe in the subrhomboidal outline and weak ornamentation.   The surface concentrics seem very similar to DUMORTIER's figure but somewhat coarser than QUENSTEDT and SCHMIDTILL's.   ROLLIER (1914) proposed *Inoceramus dumortieri* on DUMORTIER's figure, but the specific distinction seems not clear. . It is different from *Inoceramus morii* in the larger dimensions and slightly less prosocline and more elongated shell.

Occurrence:—Rare in *Hammatoceras* bed (Uh zone by ARKELL, 1956, p. 420) of Utano formation at Todani valley, west of Nishinakayama, Toyoda town, Toyora County, Yamaguchi Prefecture. Aalenian. TORIYAMA coll.

Inoceramus cf. *nitescens* ARKELL

Plate XV, Figure 15.

cf. 1933.   *Inoceramus nitescens* ARKELL, Monogr. Coral. Lamell., p. 218, pl. 28, figs. 2, 3.

Description of Japanese specimen:—Only left valve known. Shell large, highly inequilateral, roundly subrhomboidal, moderately inflated, higher than long (MM 3600, left valve, 62.5 mm. long; 71.5 mm. high; 13.0 mm. thick; obliquity ca. 55 degrees); both wings undeveloped; hinge-line as long as three-fifths of shell length, straight; anterior margin straight, not differentiated into antero-dorsal and antero-ventral, overlapped by inflated anterior part but not gaped, forming an apical angle of about 75 degrees; posterior margin broadly arcuate but forms postero-dorsal angle of about 120 degrees with hinge; umbo fairly prominent, slightly rising above hinge-line; hinge probably edentulous; ligament structure unknown; surface shining, smooth but for several subequidistant weak concentric lines; growth-lines apparently very weak.

Observation and comparison:—Represented only by a left valve. The test partly preserved on the internal surface is shiny. In view of the outline, shiny surface and weak concentric sculpture, it may be a close ally to *Inoceramus nitescens* ARKELL from the Corallian of England. The anterior margin seems slightly longer than ARKELL's type specimens, but no specific distinction can be based on any other characters.

Occurrence:—Rare in the "Nagano formation", which is correlative to Kaizara formation of the lower Tetori group, at Nagano, Izumi village, Ono County, Fukui Prefecture. Callovian or Oxfordian. Material belonging to the old collection of this institute.

Inoceramus hamadae HAYAMI, new species

Plate XV, Figures 14a, b.

Description:—Only left valve is known. Shell small, roundly subtrapezoidal, not strongly inflated, higher than long (holotype, MM 3601, left in. mould, 25.5 mm. long; 28.0 mm. high; 6.5 mm. thick; obliquity ca. 50 degress); test thin; both wings absent; postero-dorsal area not flattened, not clearly defined from remaining part; hinge-line comparatively short, passing gradually into posterior without any angulations; anterior margin straight, not gaped, turned somewhat abruptly into ventral; apical angle about 75 degrees; umbo very terminal, pointed but scarcely rising above hinge-line; hinge apparently edentulous; surface marked with about 12 irregular concentric narrow ridges and numerous growth-lines; ridges roof-shaped, clearly impressed on internal surface.

Observation and comparison:—Represented by a well preserved specimen com-

posed of left internal and external moulds. This resembles the preceding form, *I.* cf. *nitescens* ARKELL from the coeval rock in the weak ornamentation and general outline. But the dimensions are much smaller, umbo less prominent, hinge-line shorter, concentrics more irregular and the postero-dorsal corner more rounded without forming a distinct postero-dorsal angle than that form and typical *nitescens*. *Inoceramus everesti* OPPEL in HOLDHAUS (1913) from the Upper Jurassic Spiti shales is also similar in the outline, but the concentrics of that species are denser and more regular.

Occurrence:—Rare in Kaizara formation at Shimoyama, Izumi village, Ono County, Fukui Prefecture. Callovian. HAMADA coll.

Inoceramus hashiurensis HAYAMI, new species

Plate XV, Figure 16.

Description:—Only left valve known. Shell small, roundly trapezoidal, obliquely elongated, only weakly inflated, much higher than long (holotype, MM 3602, left in. mould, 26.0 mm. long; 31.0 mm. high; 4.0 mm. thick; obliquity ca. 60 degrees); both wings absent; postero-dorsal area not defined from remaining part; anterior margin prosocline, slightly concave but not gaped, forming an apical angle of about 70 degrees; umbo terminal, improminent; postero-dorsal corner rounded; hinge apparently edentulous; weak irregular concentric lamellae and numerous radial capillary threads impressed on internal surface.

Observation and comparison:—Only a left internal mould is at hand. It is similar to *Inoceramus hamadae* from the lower Tetori group, but distinct in the more obliquely elongated outline, weaker concentrics and presence of faint radial impressions on the internal surface. Such internal radials have been probably unknown in Jurassic inoceramids, but known in some Cretaceous species as "internal ribs" by NAGAO and MATSUMOTO and "Diagonalleiste" by HEINZ. But it cannot be warranted here for the radials to be homologous with those of Cretaceous species, because of the inadequate preservation of the present material.

Occurrence:—Rare in Arato formation (Nagao formation by MORI, 1949) at Kuromorizawa, Kitakami village, Monou County, Miyagi Prefecture. The age is not exactly determinable at present but must be somewhere from Bajocian to Kimmeridgian. MORI coll.

Group of *Inoceramus lucifer* VON EICHWALD

Diagnosis:—Shell medium to large, equivalve, mytiliform to subtrapezoidal, moderately or strongly inflated; umbo terminal, fairly prominent; spicial and beak angle very small; posterior wing flattened, narrow but clearly defined from remaining part; surface marked with many irregular concentric lamellae and usually also with a few strong constrictions.

Remarks:—This group may have been derived from Liassic *Parainoceramus*

or certain primitive members of *fuscus*-group, and includes several Bajocian forms from Alaska, Canada and Japan. *Inoceramus propinquus* MÜNSTER in GOLDFUSS, 1836, from the Lower Cretaceous of Germany shows similar outline and surface constrictions and may be a derivative of this group.

<center>*Inoceramus* cf. *lucifer* VON EICHWALD</center>

<center>Plate XVI, Figure 1.</center>

cf. 1871.   *Inoceramus lucifer* VON EICHWALD, Geogn. Pal. Bemerkungen Mangischlak und Aleutischen Inseln, p. 194, pl. 18, figs. 5–7.

cf. 1955.   *Inoceramus lucifer* IMLAY, *U.S. Geol. Surv., Prof. Paper, 274-D*, p. 86, pl. 8, figs. 1, 5–10.

cf. 1958.   *Inoceramus lucifer* FREBOLD, *Geol.Surv. Canada, Bull. 41*, p. 15, pl. 14, figs. 1, 2; pl. 15, fig. 2; pl. 16, figs. 1, 2.

Description of Japanese specimen:—Shell large, mytiliform, obliquely elongated, much longer than high, moderately inflated (MM 3603, left in mould, 89.0 mm. long; 51.5 mm. high; 10.5 mm. thick; obliquity ca. 30 degrees); anterior margin slightly concave, forming an apical angle of 45 degrees or slightly more; hinge-line occupying about a half shell-length; postero-dorsal angle about 150 degrees; beak angle very small, about 32 degrees; small anterior wing-like area defined from umbonal area by a shallow sulcus; posterior wing narrow, flattened, clearly defined from main body by a deep post-umbonal sulcus; surface marked with many irregular concentric lines and four distinct constrictions which become stronger towards ventral periphery.

Observation and comparison:—Represented only by a left internal mould which shows mytiloid elongated outline, small apical and beak angles and a strong constriction near ventral periphery. The specimen may be compressed secondarily in transverse direction to shell-elongation, but these characters agree with those of *Inoceramus lucifer* recently redescribed by IMLAY (1955) and FREBOLD (1958) from the Bajocian of North Alaska and Prince Patrick Island. Compared with IMLAY's plesiotypes of that species, the anterior wing seems more distinctly separated from umbonal area but other essential characters are quite similar. VON EICHWALD (1871) originally established the species as a "Neocomian or Gault one", but NEUMAYR (1885), MARTIN (1926) and many other authors shared the opinion that it is a Jurassic species. Though no clear constriction is drawn and the posterior wing seems broader in VON EICHWALD's figures, I compare this specimen with *lucifer* on the basis of the similarity to IMLAY's plesiotypes. *Inoceramus karakuwensis*, n. sp. from the adjacent horizon may be specifically different from this in view of the more orbicular outline, larger apical angle (ca. 90 degrees), absence of strong constrictions and broader postero-dorsal area. According to IMLAY and FREBOLD, *Inoceramus lucifer* is accompanied by *Pseudolioceras, Emileia, Sonninia, Stemmatoceras, Otoites* and *Arkelloceras*, and can be treated as a guide fossil of lower and middle Bajocian.

Occurrence:—Rare in the black shales of the *Stephanoceras*-bearing Tsuna-

kizaka formation at the southwest of Tsunakizaka-pass, Shishiori, Kesennuma City, Miyagi Prefecture. Middle Bajocian or thereabout.

Group of *Inoceramus retrorsus* KEYSERLING

Diagnosis:—Shell medium for genus, equivalve, subtrapezoidal to cuneiform in outline; umbo terminal; apical angle comparatively small; postero-dorsal area well-defined from remaining part by post-umbonal sulcus, flattened, more or less auriculate; strong constrictions not appear; concentric ornamentation and other characters similar to those of the group of *I. fuscus.*

Remarks:—This group composed of a few arctic and two Japanese species chiefly from the Bathonian and Callovian is probably related to the group of *I. fuscus,* but characterized by the more cuneiform outline and better defined and more developed posterior wing.

Inoceramus utanoensis KOBAYASHI

Plate XVI, Figures 3–5.

1926. *Inoceramus utanoensis* KOBAYASHI, *Jour. Geol. Soc. Tokyo, Vol. 33,* p. 7, pl. 11, figs. 1–2.

Description:—Shell small to large, equivalve, subrhomboidal to cuneiform, as long as or slightly longer than high; anterior wing absent, while posterior one is large, flattened and clearly defined from remaining surface by a post-umbonal sulcus; anterior margin straight, long, not differentiated into antero-dorsal and antero-ventral; posterior margin of wing sometimes slightly sinuated but passing gradually into broadly arcuate ventral margin; umbo narrow, fairly prominent but scarcely rising above hinge-line; hinge occupying about two-thirds of shell-length; apical angle somewhat variable among individuals but usually 55 to 65 degrees in cotypes; postero-dorsal angle about 120 degrees; ligament area apparently narrow; pits numerous; hinge edentulous; surface marked with several concentric ribs which are flattened at bottoms and fairly irregular in interval and prominence, and numerous slightly imbricated growth-lamellae; concentric ribs much weakened towards postero-dorsal area.

Measurement in mm.		Length	Height	Thickness	Obliquity
Lectotype	(MM 9081) bivalved in. mould	45.0	43.5	11.0	50°
Cotype	(MM 9085) left valve (juv.)	23.0	19.5	6.5	45°
Cotype	(MM 9084) left ex. mould	44.5	47.0	9.0	45°

Observation and comparison:—Among KOBAYASHI's cotypes I select here a bivalved internal mould (fig. 1 in KOBAYASHI, 1926) as the lectotype. Though the outline is variable to a certain extent among individuals, this species can be generally characterized by the small beak angle (ca. 30 degrees) and clearly defined and well developed posterior wing. These characters remind me at a glance of those of *Cuneigervillia* COX, 1954, which was established as a substitute of *Edentula* WAAGEN, 1907, non NITSCH, 1820, but considered to be dis-

tinct from WAAGEN's by TOKUYAMA (1959)*. However, this is anyhow different from *Cuneigervillia* in the thin test, narrower ligament area with more numerous pits and concentric sculpture of *Inoceramus*-type. As noted by KOBAYASHI (1947), this species may be similar to *Inoceramus retrorsus* KEYSERLING, 1848, (LAHUSEN 1886), but the more cuneiform outline and developed posterior wing prevent me from referring this to *retrorsus*. A small specimen, which must be conspecific with the lectotype from the same bed, has less cuneiform outline and may suggest that this species is related also to the group of *I. fuscus*.

Occurrence:—Common in the upper part of Utano formation at Utano, Okaeda village, Toyora County, Yamaguchi Prefecture. Callovian or thereabout. KOBAYASHI coll.

Inoceramus ogurai KOBAYASHI

Plate XVI, Figure 2.

1926. *Inoceramus ogurai* KOBAYASHI, *Jour. Geol. Soc. Tokyo, Vol. 33*, p. 7, pl. 11, fig. 3.

Description:—Shell medium, subtrapezoidal, not strongly inflated, higher than long (holotype, MM 9086, 58.0 mm. long; 63.0 mm. high; 10.5 mm. thick; obliquity ca. 60 degrees); anterior margin fairly convex, forming apical angle of about 90 degrees or slightly less with hinge-line; hinge fairly long, occupying about two-thirds of length; posterior wing large, triangular, flattened, sharply defined from remaining part; posterior margin behind it slightly sinuated, forming a postero-dorsal angle of about 110 degrees; beak angle about 50 degrees; umbo terminal, slightly projecting above hinge; surface but for posterior wing about 30 or more concentrics.

Observation and comparison:—Besides the holotype specimen, two fragmental moulds showing similar surface sculpture are referrable to this species. The developed posterior wing and general outline are similar to *Inoceramus utanoensis* KOBAYASHI, but distinguishing characters from that species are the larger apical angle and shell-obliquity, more convex anterior margin and more delicate surface sculpture. The resemblance of outline between this species and *Cuneigervillia* cannot be overlooked, but in all species of that genus listed by Cox (1954) the umbo is more anteriorly projected and more prosogyrous.

Occurrence:—The same as the preceding species. Callovian or thereabout. KOBAYASHI coll.

Group of *Inoceramus galoi* BOEHM

Diagnosis:—Shell medium to large for genus, eqivalve, variable in outline but usually subovate and sometimes elongated, moderately inflated; anterior margin very prosocline, ill-differentiated into antero-dorsal and antero-ventral; apical angle comparatively small (45-80 degrees); beak angle usually im-

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* TOKUYAMA proposed *Waagenoperna* as a substitute name of *Edentula* WAAGEN and included it in the Isognomonidae.

measurable, because of the ill-defined postero-dorsal area; both wings absent; postero-dorsal angle rounded and very large; surface marked with wide-spaced regular concentric foldings.

Remarks:—This group, which seems common in the Oxfordian and later of Himalaya, Moluccas, New Caledonia and New Zealand, is charcterized by the subovate outline and coarse concentric ribs. Certain species such as *Inoceramus everesti* OPPEL seems intermediate between *fuscus*- and this group in many respects. This group can be subdivided into *galoi*-subgroup with small apical angle (ca. 50 degrees) and *haasti*-subgroup with large apical angle (ca. 75 degrees), as pointed out by WANDEL (1936).

Inoceramus sp. ex gr. *galoi* BOEHM

Plate XVI, Figure 6.

ex gr.

1907. *Inoceramus galoi* BOEHM, *Palaeontogr., Supple. 4, Lief. 2*, p. 68, pl. 9, figs. 10–14; pl. 10, figs. 1, 2.

1923. *Inoceramus* cf. *galoi*, TRECHMANN, *Quart. Jour. Geol. Soc. London, Vol. 79*, p. 274, pl. 15, figs. 1, 2.

1926. *Inoceramus* sp. ex gr. *galoi*, JAWORSKI, *Actas Acad. Noc. Cienc., Vol. 9, Nos. 3–4*, p. 158.

1936. *Inoceramus galoi* WANDEL, *Neues Jahrb. f. Min. usw., Beil.-Bd. 75B*, p. 467, text-fig. 2.

1953. *Inoceramus galoi* MARWICK, *N. Z. Geol. Surv., Pal. Bull. 21*, p. 92, pl. 12, fig. 2.

1953. *Inoceramus* sp. (aff. *I.* cf. *galoi* BOEHM in TRECHMANN), AVIAS, *Univ. Nancy, Fac. Sci., Thesis No. 91*, p. 169, pl. 23, figs. 1, 2, 7.

1959. *Inoceramus* cf. *galoi*, MILLIGAN, *N. Z. Jour. Geol. Geoph., Vol. 2, No. 1*, p. 197, text-fig. 2.

Represented by a fragmental external mould. Judging from the concentric ribs, this form is fairly large and has somewhat obliquely elongated outline. MORI (1949, p. 319) compared this specimen with *Inoceramus haasti*, but I presume that it may be more close to *Inoceramus galoi* BOEHM in view of the mode of round-topped concentric ribs.

Occurrence:—Rare in the black shale of Arato formation (Nagao shales in MORI, 1949) at Kuromorizawa, north of Ookami, Kitakami village, Monou County, Miyagi Prefecture. The age is exactly indeterminable but somewhere from Bajocian to Kimmeridgian. MORI coll.

Group of *Inoceramus neocomiensis* D'ORBIGNY

Diagnosis:—Shell medium to very large, subequivalve to pronouncedly inequivalve, variable in outline but usually subovate or polygonal and not much elongated, more or less higher than long; left valve frequently more strongly inflated than right, provided with more prominent umbo; anterior margin often differentiated into antero-dorsal and antero-ventral, subvertical or even opisthocline; apical angle 90 degrees or more; postero-dorsal area not auriculate, sometimes fairly wide but not clearly defined; prismatic layer fair-

ly thick; hinge edentulous; ligament area comparatively long; pits isolated from one another; surface marked with numerous densely and sometimes slightly imbricated concentric wrinkles; strong concentric and radial plications absent.

Remarks:—WOODS (1911) stated that the species of Gault, upper Greensand and Chalk *Inoceramus* appear to be originated from two lower Greensand stocks, one being *Inoceramus salomoni* D'ORBIGNY and the other belonging to the type of *Inoceramus necomiensis* D'ORBIGNY. According to GILLET (1924), *Inoceramus ewaldi* SCHLÜTER, *I. quatsioensis* WHITFIELD, *I. ovatus* STANTON, *I. montezumae* FELIX, *I. plicatus* D'ORBIGNY, *I. picteti* MAYER-EYMAR and *I. sebianus* BUCHAUER belong to the group of *I. neocomiensis*. Besides, *Inoceramus anglicus* WOODS from the upper Greensand and Gault seems to belong also to the group. *Inoceramus tenuis* MANTELL, 1822, from the Albio-Cenomanian resembles some species of this group, but WOODS regarded it as a descendant of *Inoceramus salomoni*, which has a fairly striking sulcus on the middle surface and short triangular ligament area with divergent pits from beak. The ligament structure which reminds me of a primitive multivincular pelecypod, is quite different not only from Cretaceous but also from Jurassic species, and may imply that it was derived directly from other family than the Inoceramidae. *Salomoni* is generally considered as ancestral to the group of *Inoceramus concentricus* PARKINSON from the Middle and Upper Cretaceous, but I presume that the former species is somewhat deviated from the main trunk of the family which was persistent from the Jurassic. This group is characterized by the large and regular and delicate surface sculpture, and readily distinguishable from above mentioned Jurassic groups. So far as I am aware, no inquivalve inoceramid has been reported from the Jurassic. However, the following species show very inequivalve shells, prominent umbones and large apical angles, and are referable to *neocomiensis*-group.

Inoceramus maedae HAYAMI, new species

Plate XVII, Figures 1–3; Text-figure 2.

1952. *Inoceramus* spp., MAEDA, *Jour. Geol. Soc. Japan, Vol. 58, No. 679*, p. 150 (pars).

Description:—Shell large to very large, inequivalve, subquadrate or polygonal in outline, more or less higher than long; test thin; left valve strongly inflated, while convexity of right valve is moderate; anterior margin differentiated into slightly concave opisthocline antero-dorsal and prosocline antero-ventral of similar length; anterior wing absent but anterior area fairly protruded forwards beyond umbo; apical angle between antero-dorsal and hinge-margins about 115 degrees in right valve and probable slightly larger in left; posterior wing absent; posterior margin broadly arcuate from posterior part of hinge-margin; posterior area not defined and beak angle immeasurable in left valve, but in right valve a weak post-umbonal sulcus present and forming an beak angle of about 90 degrees with antero-dorsal; hinge-line occupying
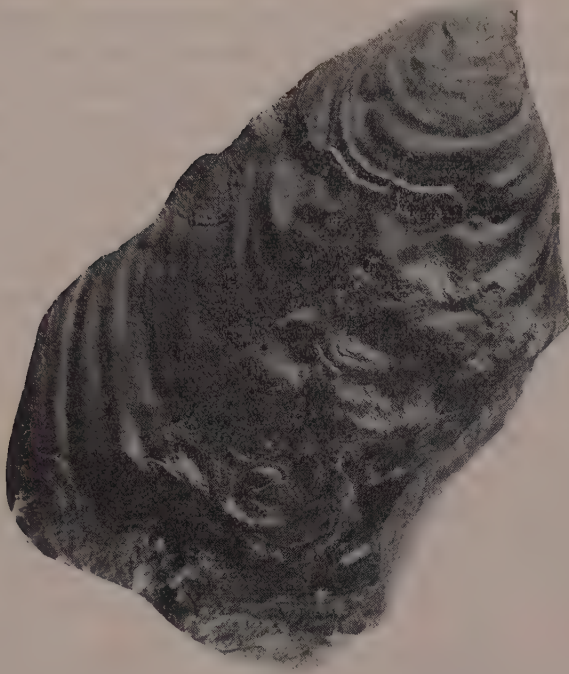
Text-figure 2. Right valve of *Inoceramus
maedae* HAYAMI, n. sp. (MM 9069) from the
Mitarai formation, ×3/4. MAEDA coll.

about a half of little more of shell-length; umbo terminal but situated at
about a fifth of shell-length from anterior extremity of shell, very prominent,
recurved and rising highly above hinge in left valve, but less prominent and
scarcely protruded in right valve; hinge edentulous; ligament area occupying
greater part of hinge-margin, comparatively narrow, slightly concave and
forming a certain angle against commissure plane in right valve, provided
with numerous pits which are much broader than their interspaces; surface
marked with numerous subequidistant concentric lamellae which are slightly
imbricated externally and weakly impressed on internal surface; mode of
ornamentation equal between two valves; strong plication and constriction
absent; test occupied mostly by developed prismatic calcite layer; prisms
about 0.1 mm. in diameter, interfingering from outer and inner margins, show-
ing very irregular extinction under cross nicol.

Measurement in mm.	Length	Height	Thickness	Obliquity
Holotype (MM 9076) right valve	104.0	114.5	17.5	70°
Paratype (MM 9077) right in. mould	68.0	77.0	11.5	75°
Paratype (MM 9078) left valve	62.5	72.0	29.0	70°

Observation and comparison:—Three well preserved specimens and many
f ragments are at hand. The remarkable inequivalveness is ascertained be-

tween the holotype (right) and paratype (left) specimens which show similar
surface markings and outlines. The holotype specimen is composed of nearly
complete internal and broken external moulds. The test is partly but well
preserved on the latter mould. The microscopic observation was carried out
on several thin sections prepared from the holotype and some other fragmental
specimens (Pl. XVII, Figs. 3b, c). In all rectangular sections to shell-surface, the
test is occupied by developed calcite prisms, and lamellar layer cannot be ob-
served, though it is unknown whether the layer is very thin or not preserved
by unfavourable preservation. In parallel sections to shell-surface, the test
is filled by numerous polygonal prisms which show very irregular extinction
under cross nicol. The concave and narrow ligament area is impressed on the
internal surface of the paratype. In view of the strong inequivalveness, large
dimensions and large apical angle, this species is different from hitherto
known Jurassic inoceramids and more similar to the group of *Inoceramus
neocomiensis* chiefly from the Neocomian and Gault. Specifically it resembles
Inoceramus anglicus WOODS, 1911, from the Albian in the outline of right valve,
but the shell is more inequivalve and the umbo of left valve much more pro-
minent than the Albian species. The concentric ornamentation is seemingly
weaker and denser. The inequivalveness may remind one of some varietal
forms of *Inoceramus concentricus* PARKINSON, 1819, from the Middle and Upper
Cretaceous, but the umbonal region of each valve is less prominent and broa-
der, hinge-line longer and the dimensions are much larger. *Inoceramus tenuis*
MANTELL, 1822 (WOODS, 1911) from the Albio-Cenomanian shows similar inequi-
valve outline and delicate concentrics. According to WOODS, *I. tenuis* resem-
bles *I. concentricus* but the left umbo is less prominent, the length of shell is
relatively greater and concentric rings less prominent. Such differences are
found also between *concentricus* and this species. Compared with WOODS'
figures (1911-1912, p. 272-273, text-figs. 31-32) the outline seems more trapezoidal
and postero-dorsal area is broader, but another figure (pl. 48, fig. 1) shows
broader outline and more projected postero-dorsal area. Though it may be
difficult that the specific distinction can be based on the outline and ornamen-
tation, this is, I think, not conspecific with *tenuis* in view of the broadly
sinuated antero-dirsal margin and more developed anterior area which projected
forwards beyond umbo. *Inoceramus neocomiensis* D'ORBIGNY, 1842, from the
Neocomian of Europe and South America differs from this in the gibbose out-
line and ill-differentiated anterior margin. The species includes two varietal
forms which are probably conspecific but somewhat different in morphology.

Occurrence:—Common in the lower part of Mitarai formation (M_1 member
by MAEDA, 1952a and HAYAMI, 1959b) at Mitarai, Shokawa village, Ono County,
Gifu Prefecture. MAEDA suggested that this formation is as a whole cor-
relative with the Callovio-Oxfordian Kaizara formation in Kuzuryu area. But
my palaeontological result shows that the Mitarai fauna comprises several
pelecypods akin to some Uppermost Jurassic and Lower Cretaceous foreign
species. This inoceramid is, as noted above, more similar to some Neocomian
and Gault species than any Upper Jurassic ones. The age is exactly indeter-

minable at present, but concluded to be more or less younger than the Kaizara fauna. Some inoceramids from Kaizara are less inflated, smaller, subrhomboidal, more primitive and properly belong to *fuscus*-group. It is interesting that the marine invasions, whose sediments are represented in the Tetori group, appear to have occurred at different stages among Kuzuryu, Makito and Kiritani areas. MAEDA coll.

Inoceramus maedae HAYAMI, var. a

Plate XVI, Figure 7; Plate XVIII, Figure 2.

Description:—Only left valve is known. Shell medium to very large, subrectangular, moderately inflated, much higher than long; test thin; umbo fairly prominent but rising slightly above hinge-line; surface marked with several irregular concentric foldings and numerous slightly imbricated lamellae of *maedae*-type.

Measurement in mm.	Length	Height	Thickness	Obliquity
(MM 9070) left valve	110. 5	152. 5	31. 0	70°
(MM 9078) left ex. mould	50. 0	51. 0+	19. 5	70°

Observation and comparison:—This form represented by two specimens is probably conspecific with *Inoceramus maedae* from the same locality, judging from the large obliquity and similar concentric lamellae, but it is somewhat different in the less prominent umbo and the presence or more elevated concentric ribs and weak constrictions. Since the anterior marginal areas of the two specimens, which seem at a glance nearly acline, are broken, the umbonal angle may be larger than 90 degrees. The precise comparison of outline with typical *maedae* is, therefore, difficult.

Occurrence:—The same as *Inoceramus maedae*. MAEDA coll.

Inoceramus maedae HAYAMI, var. b

Plate XVIII, Figure 1.

An intact specimen has also inequivalve shells and prominent umbo of left valve, but shows exceptionally small apical angle (about 75 degrees) and ill-developed anterior area. Judging from the somewhat emphasized concentrics in antero-ventral area, this specimen (MM 9071) is probably compressed secondarily in diagonal direction, and it may be merely a varietal form of *Inoceramus maedae*.

Occurrence:—The same as *Inoceramus maedae*. MAEDA coll.

Inoceramus furukawensis HAYAMI, new species

Plate XVI, Figure 8.

Description:—Shell medium, scborbicular, well inflated, slightly higher than

long (holotype, MM 3604, left in. mould, 46.5 mm. long; 52.0mm. high; 13.5mm. thick; obliquity ca. 75 degrees); anterior margin slightly concave, slightly opisthocline, forming an apical angle of about 115 degrees; hinge-line occupying about three-fourths of shell-length, gradually bent down into posterior without sharp angulation; both wings absent; postero-dorsal area weakly defined but narrow; umbo terminal, recurved, fairly prominent, rising highly above hinge-margin; ligament area comparatively wide, provided with numeous pits along greater part of hinge-line; inner surface smooth but for several obscure concentric foldings.

Observation and comparison:—Represented only by an internal mould of left valve which shows the internal characters prominent and thickened umbonal area. The test may be thick for *Inoceramus*, but the prominent umbo and multivincular ligament structure are typical of the genus. Although the inequivalveness cannot be ascertained, the strong inflation, concave and opisthocline antero-dorsal margin, large apical angle and weak ornamentation show that this is akin to *Inoceramus maedae* from Makito. The ligament structure is also very similar. However, the dimensions of this specimen are much smaller and the hinge-margin somewhat longer and thicker than that species.

Occurrence:—Rare in fine sandstone of Sugizaki sandy formation at Wakidani, Kawai village, Yoshiki County, Gifu Prefecture. MAEDA (1958) reported *Nipponitrigonia* sp. from this horizon. The age cannot be exactly determined but presumed to be almost contemporaneous with the Oxfordian Kiritani formation. AMAFUJI, OGASAWARA and TAKAGI coll. The tribal name in their manuscript (1949) is applied in the present specific denomination.

Incertae sedis

Several other Jurassic inoceramids in Japan are more or less aberrant and cannot be included in the above mentioned groups.

Inoceramus (s. l.) *kudoi* HAYAMI, new species

Plate XVI, Figure 9; Plate XVIII, Figures 3–4.

Description:—Shell medium to very large, equivalve, mytiliform, elongated postero-ventrally, not strongly inflated, much longer than high; anterior margin straight, unusuall long, forming an apical angle of about 45 degrees with hinge; hinge-line occupying about a half length, passing gradually into posterior margin which is subparallel to anterior; both wings absent; postero-dorsal area not defined; umbo terminal, pointed but improminent, not rising above hinge; hinge edentulous; ligament area narrow, provided with 10 or more pits; surface smooth except for faint concentric lines of growth.

Measurement in mm.	Length	Height	Thickness	Obliquity
Holotype (MM 9088) left in. mould	114.0	84.5	12.0	30°
Paratype (MM 9089) right in.mould	110.0	91.0	14.5	30°
Paratype (MM 9090) left in. mould	50.0+	44.0+	9.0	35°
Paratype (MM 9093) right ex. mould	35.0	25.5	4.5	30°

Observation and comparison:—Seven specimens at hand have similarly mytili-
form and elongated outline. Although the outline reminds at a glance one of
the Mytilidae or Pinnidae rather than Inoceramidae, the multivincular liga-
ment structure shows this to belong to the Isognomonidae or Inoceramidae.
Mesozoic isognomonids have usually thick tests, broad ligament area with
subvertically elongated pits and more or less gaped anterior margin, while
this species is characterized by the thin shell and narrow ligament. Mytili-
form isognomonids are generally referred to subgenus *Mytiloperna* ROLLIER,
which is, however, characterized by the comparatively small dimensions and
also thick test. Some specimens of *Waagenoperna triangularis* (KOBAYASHI and
ICHIKAWA, 1952) from the Upper Triassic Nariwa and Mine groups (TOKUYAMA,
1959) resembles this, but the outline is more mytiliform and more elongated
than that species. In view of the impriment umbo and weak ornamenta-
tion, this is anyhow not a typical inoceramid, and the generic reference is
provisional. So far as I am aware, there is no comparable species with this
in Japanese and foreign Jurassic.

Occurrence:—Common in the upper part of Hosoura shaly formation (*Ham-
matoceras*-bed or Hh zone by SATO, 1957) at Jaou and some other localities,
Hosoura, Shizukawa town, Motoyoshi County, Miyagi Prefecture. Aalenian.
KOBAYASHI, KUDO and SATO coll.

Inoceramus (s. l.) *fukadae* HAYAMI, new species

Plate XVI, Figure 10; Text-figure 3.

Description:—Only left valve known.
Shell small to medium, elliptical, mod-
erately inflated, much longer than high;
both wings absent; anterior margin
broadly convex, passing gradually into
venter without any angulations; apical
angle obtuse but accurately inmeasur-
able; hinge-line long, occupying about
three-fourths of shell-length; postero-
dorsal angle about 130 degrees; postero-
dorsal area narrow, ill-defined; umbo
fairly prominent, rising above hinge-
line; hinge apparently edentulous; liga-
ment area fairly wide, provided with
somewhat roughly spaced ligament pits;

Text-figure 3. Left internal mould
of *Inoceramus* (s. l.) *fukadae* HAYAMI,
u. sp. (MM 3606), paratype, from the
Aalenian or Bajocian at Kodaijima,
×3/4. FUKADA coll.

surface marked with several concentric foldings.

Measurement in mm.	Length	Height	Thickness	Obliquity
Holotype (MM 3605) left in. mould	31. 5	25. 5	8. 0	45°
Paratype (MM 3606) left in. mould	69. 0	53. 5	17. 0	45°

Observation and comparison:—Represented by three specimens. Although they may be more or less deformed secondarily, the elliptical outline and long hinge-line occupying almost the shell-length are fairly unique for Jurassic inoceramids. The prominent umbo, concentric sculpture and multivincular ligament imply this species to belong to *Inoceramus* of a wide sense, but its taxonomic position is uncertain, since I could not refer to any intimate species.

Occurrence:—Rare in the *Inoceramus*-bed of Kodaijima sandy formation at the southern coast of Kodaijima (an island at the neck of the Ojika peninsula), Ishinomaki City, Miyagi Prefecture. Aalenian or Bajocian. FUKADA coll.

Inoceramus (s. l.) a sp. indet.
Text-figure 4.

A fragment of a large inoceramid (MM 3607) differs from *Inoceramus* (s. l.) *fukadae* in the much larger dimensions and broadly plicated concentric ribs. The mode of ornamentation is somewhat similar to that of *galoi*-group.

Occurrence:—The same as *Inoceramus* (s. l.) *fukadae*. FUKADA coll.

Text-figure 4. *Inoceramus* (s. l.) a sp. (MM 3607) from the Aalenian or Bajocian at Kodaijima, ×1/2. FUKADA coll.
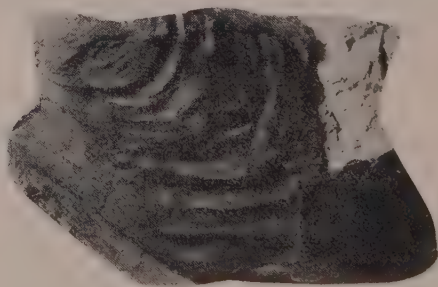
Text-figure 5. *Inoceramus* (s. l.) b sp. (MM 3608) from the Bajocian at the southeast of Tsunakizaka, ×3/4. YAMASHITA coll.

Inoceramus (s. l.) b sp. indet.
Text-figure 5.

A fragment of right valve (MM 3608) has similarly irregular concentrics to *Inoceramus utanoensis* KOBAYASHI from Utano formation, but the apical angle

is apparently larger. Judging from the deformation of associated fossils, this specimen is also compressed secondarily. It may belong to a different species from *Inoceramus karakuwensis* from the same horizon, since the posterior area is worse defined and concentrics less prominent.

Occurrence:—Rare in the *Stephanoceras*-bearing Tsunakizaka formation at the southeast of Tsunakizaka-pass, Shishiori, Kesennuma City, Miyagi Prefecture. Middle Bajocian or thereabout. YAMASHITA coll.

Inoceramus (s. l.) c sp. indet.

Plate XVI, Figure 11.

A small external mould (MM 3609), though specifically indeterminable, is referable to *Inoceramus* of a wide sense in the thin test, concentric ornaments and developed prisms which are fairly characteristic of the genus.

Occurrence:—Rare in tuffaceous siltstone (M_2 by MAEDA, 1952a and HAYAMI, 1959b) of Mitarai formation at the west of Mitarai, Shokawa village, Ono County, Gifu Prefecture. Upper Jurassic or Lower Cretaceous.

Inoceramus (s. l.) d sp. indet.

Plate XVIII, Figure 5.

Only a left valve is available. Shell very small, mytiliform, obliquely elongated, moderately inflated, higher than long (MM 3610, left valve, 15.0 mm. long; 18.0 mm. high; 3.5 mm. thick); anterior margin long, nearly straight; apical angle about 80 degrees; postero-dorsal angle about 135 degrees; hinge-line occupying about three-fifths of shell-length; umbo subterminal, slightly rising above hinge; postero-dorsal area not defined; surface smooth except for fine concentric growth-lamellae; hinge and ligament structure unknown.

The outline is similar to some species of *Parainoceramus* instead of Upper Jurassic and Lower Cretaceous developed species. *Inoceramus* cf. *amygdaloides* GOLDFUSS in SCHMIDTILL (1926) resembles this, but the shell-obliquity and apical angle are larger than that form. This may be a new form, but the specific name is not given here, since the occurrence of this specimen is exactly unknown.

Occurrence:—This specimen belongs to an old collection of this institute, labelled to have been collected from "Yoshimo". As stated KOBAYASHI and SUZUKI (1939) and MATSUMOTO (1953), the Yoshimo beds of West Japan must be Lower Cretaceous (or Wealden) and included in the Toyonishi group. All the fossils of Yoshimo beds appear brackish and the location of this specimen is now uncertain.

Inoceramus (?) *naganoensis* HAYAMI, new species

Plate XVIII, Figure 6.

Description:—Shell medium, *Isognomon*-like in outline, weakly inflated, much

higher than long (holotype, MM 3611, 49.5 mm. long ; 64.5 mm. high ; 9.0 mm. thick ; obliquity ca. 60 degrees) ; anterior margin broadly sinuated, forming an apical angle of about 80 degrees ; posterior margin broadly convex, subparallel to anterior margin ; hinge-line fairly long, occupying about three-fourths of shell-length ; umbo terminal, projected forwards, situated at the anterior extremity of shell ; internal surface marked with some irregular concentric foldings.

Observation and comparison :—Represented by two specimens. Since the test is exfoliated and ligament structure not observable, it cannot be determined whether it is actually an inoceramid or a member of *Isognomon*. The improminent umbo projected forwards is similar to some species of Mesozoic *Isognomon*, but the surface markings remind me of *Inoceramus*. This is somewhat similar to *Inoceramus* aff. *everesti* Oppel in Marwick, 1953, from the Ohauan (≒Kimmeridgian) of New Zealand, but the concentrics seem more irregular.

Occurence :—Rare in the black shale of the "Nagano formation" which is correlative with Kaizara formation, at Nagano, Izumi village, Ono County, Fukui Prefecture. Callovian or Oxfordian.

Synoptic List of Jurassic Inoceramids

Abbreviations :

    P : *Parainoceramus*
    Ip : Group of *Inoceramus polyplocus* (subgenus *Mytiloceramus*)
    If : Group of *Inoceramus fuscus*
    Il : Group of *Inoceramus lucifer*
    Ir : Group of *Inoceramus retrorsus*
    Ig : Group of *Inoceramus galoi*
    In : Group of *Inoceramus neocomiensis*
    Io : Other groups of *Inoceramus*

Inoceramus ambiguus von Eichwald, 1865, p. 493, pl. 21, f. 8a, b, Moscow ; von
    Eichwald, 1871, p. 189, pl. 20, f. 1-5, Alaska ; aff., Spath, 1932, p. 109, text-
    fig. 7, mid. Greenland. (Ir) Bathonian-Callovian.

Inoceramus amygaloides Goldfuss, 1836, p. 110, pl. 115, f. 4, Germany ; Roemer,
    1836, p. 83 ; Oppel, 1856–1858, p. 416, (=*I. ellipticus* Roemer, 1836, according
    to Rollier, 1914) ; Seebach, 1864, p. 108, do. ; Pčelinčev, 1933, p. 12, pl. 2,
    f. 20-23, Caucasus ; Pčelinčev, 1937, p. 50, 70, pl. 3, f. 53-58, do. ; aff.,
    Bodylevski and Shulgina, 1958, p. 61, Yenisei. (?=*Mytilites elongatiformis*
    Schlotheim, 1820). (P) Toarcian-Aalenian.

Inoceramus anomiaeformis Feruglio, 1936, Patagonia. Tithonian or Neocomian.

Inoceramus apollo Leanza, 1942, p. 157, pl. 2, f. 1, Neuquén. (P) Pliensbachian.

Inoceramus aucella Trautschold, 1865, p. 4, pl. 1, f. 2-3, Ssimbirsk. ? Jurassic.

Inoceramus balinensis Rollier, 1914, p. 423, Germany. (=*I. fuscus* Laube, 1867,
    non Quenstedt, 1856). (If) Callovian.

Inoceramus brownei Marwick, 1953, p. 92, pl. 13, f. 17, pl. 14, f. 5, New Zealand.
    (Io) Bajocian-Bathonian.

Inoceramus brunneri Ooster, 1869, p. 38, pl. 13, f. 7-14, Alps. (→*I. oosteri* Favre,

1876). (If or In) Oxfordian.

Parainoceramus bulkurensis Voronetz, 1936, p. 34, pl. 1, f. 2, 8, 10, North Siberia; Cox, 1954, p. 47, do. (P) Upper Triassic.

Inoceramus cinctus Goldfuss, 1836, p. 110, pl. 115, f. 5, Germany; Roemer, 1836, p. 82, do.; Dumortier, 1874, p. 185, France; Jenensch, 1902, p. 24, pl. 10, f. 2, Germany; Rollier, 1914, p. 420, listed; Pčelinčev, 1937, p. 51, 71, pl. 3, f. 59, Caucasus. (P) Toarcian.

Inoceramya concentrica Ulrich, 1910, p. 134, pl. 12, f. 1, 2, pl. 13, f. 1, Alaska. (non *Inoceramus concentricus* Parkinson, 1819). (*Inoceramya*) Yaktat group (Jurassic ?).

Inoceramus cor Münster in Goldfuss, 1836, p. 111, pl. 109, f. 7, Germany; von Eichwald, 1865, p. 485, Crimea. (If ?) Jurassic.

Inoceramus corfinianus Fucini, Italy; Marino, 1934, do. Lias.

Inoceramus depressus Münster in Goldfuss, 1836, p. 109, pl. 109, f. 5, Germany; Rollier, 1914, p. 417, listed. (=*I. ventricosus* Sowerby according to Brauns, 1871). (P) Hettangian-Sinemurian.

Inoceramus dubius Sowerby, 1826, p. 162, pl. 584, f. 3, England; Zieten, 1830, p. 96, pl. 72, f. 6, Germany; Goldfuss, 1836, p. 108, pl. 109, f. 1, Germany (→ *I. polyplocus* Roemer, 1857); Quenstedt, 1856, p. 260, Germany; Dumortier, 1874, p. 186, pl. 42, f. 5–6, France; Rollier, 1914, p. 419, listed; Jaworski, 1926, p. 158, Argentian; Pčelinčev, 1928, p. 1117, pl. 56, f. 13–14, Caucasus; Pčelinčev, 1933, p. 11, pl. 2, f. 15–19, do.; Pčelinčev, 1937, p. 50, 70, pl. 3, f. 48–52, do.; Gillard, 1940, p. 609, France; cf., Thevenin, 1908, p. 24, pl. 3, f. 10, Madagascar; cf., Frebold, 1957, p. 11, Alberta. (P) Toarcian-Aalenian.

Inoceramus dumortieri Rollier, 1914, p. 421, France. (=*I. fuscus* Dumortier, 1874, non Quenstedt, 1856). (If) Aalenian.

Inoceramus ellipticus Roemer, 1836, p. 82, Germany; Quenstedt, 1856, p. 355, Germany; Rollier, 1914, p. 421, listed. Aalenian-Bajocian.

Inoceramus everesti Oppel, 1862, p. 298, Himalaya; Holdhaus, 1913, p. 415, pl. 98, f. 12–14, Himalaya; aff., Marwick, 1953, p. 92, pl. 12, f. 4, New Zealand. (If ?) Tithonian.

Inoceramus eximius von Eichwald, 1871, p. 192, pl. 18, f. 1–4, pl. 19, f. 3–4, Alaska. (Ir) Jurassic.

Inoceramus expansus Blake, 1875, p. 229, pl. 12, f. 3–4, England. (non *I. expansus* Baily from Cretaceous). (If) Kimmeridgian.

Inoceramus faberi Oppel, 1856–1858, p. 101, Germany; Rollier, 1914, p. 417, listed. Hettangian.

Inoceramus falgeri Merian, 1853, p. 7, pl. 1, Alps; Ooster, 1869, p. 36, pl. 12, f. 1–5, do.; Rollier, 1914, p. 418, listed. (P or If) Pliensbachian.

Inoceramus ferniensis Warren, 1932, p. 15, pl. 2, f. 1–3, Alberta. (Ir ?) Dogger ?.

Inoceramus fittoni Morris and Lycett, 1853, p. 24, pl. 3, f. 14, England; Moesch, 1874, p. 38, Swiss; Rollier, 1914, p. 423, listed; Cox and Arkell, 1948, p. 11, England. (If) Bathonian-Callovian.

Inoceramus (s. l.) *fukadae* Hayami, n. sp., p. 313, pl. 16 f. 10, Japan. (Io) Aalenian.

Iuoceramus furukawensis Hayami, n. sp., p. 311, pl. 16, f. 8, Japan.　(In)？ Oxfordian.

Inoccramus fuscus Quenstedt, 1856, p. 355, pl. 48, f. 18, Germany; Moesch, 1867, p. 73, Swiss; Laube, 1867, p. 26, pl. 2, f. 1, Germany (→*I. balinensis* Rollier, 1914); Ooster, 1869, p. 38, pl. 13, f. 1–6, Alps; Dumortier, 1874, p. 307, p. 61, f. 6–7, France (→*I. dumortieri* Rollier, 1914); Rollier, 1914, p. 422, listed; Schmidtill, 1926, p. 17, pl. 3, f. 3, Germany; Wetzel, 1950, p. 108, Germany; ex gr., Hayami, 1960, p. 301, pl. 15, f. 13, Japan.　(If) Calenian-？ Bajocian.

Inoceramus galoi Boehm, 1907, p. 68, pl. 9, f. 10–14, pl. 10, f. 1–2, Sulu; Wandel, 1936, p. 467, text-figs., Sulu; Marwick, 1953, p. 92, pl. 12, f. 2, New Zealand; cf., Trechmann, 1923, p. 274, pl. 15, f. 1–2, New Zealand; ex gr., Jaworski, 1926, p. 158, Argentian; aff. I. cf. galoi Trechmann, Avias, 1953, p. 169, pl. 23, f. 1, 2, 7, New Caledonia; cf., Milligan, 1959, p. 197, f. 2, New Zealand; ex gr., Hayami, 1960, p. 107, pl. 16, f. 6, Japan. (Ig) Callovian-Oxfordian？ Tithonian.

Parainoceramus？ gervillia Voronetz, 1936, p. 34, pl. 1, f. 11, North Siberia.　(P？) Upper Triassic.

Inoceramus gracilis Holdhaus, 1913, p. 417, pl. 98, f. 15, Himalaya.　(Ig) Tithonian.

Mytilus gryphoides Schlotheim, 1820, p. 296, Germany; *Inoceramus gryphoides* Goldfuss, 1836, p. 109, pl. 115, f. 2, Germany; Quenstedt, 1856, p. 260, pl. 37, f. 11, 12, up. Lias, Germany; Pčelinčev, 1933, p. 14, pl. 1, f. 7, Caucasus; Pčelinčev, 1937, p. 51, 71, pl. 4, f. 7, 8, Caucasus.　(P) Pliensbachian-Toarcian.

Inoceramus gryphaeoides (Schlotheim), von Eichwald, 1865, p. 496, Tambov and Lithuania.　(？ misspelling of *gryphoides*) "Oxfordian".

Inoceramus haasti Hochstetter, 1863, p. 190, New Zealand; Zittel, 1864, p. 33, pl. 8, f. 5, New Zealand; Boehm, 1911, p. 14, Sulu; Wandel, 1936, p. 473, pl. 19, 20, text-fig. 4, 5, Misol; Bartrum, 1937, p. 458, f. 1, New Zealand; Marwick, 1953, p. 91, pl. 12, f. 1, up. New Zealand; cf., Trechmann, 1923, p. 275, pl. 15, f. 3, New Zealand; cf., Krumbeck, 1923, p. 78, pl. 173, f. 13, low. Timor.　(Ig) Oxfordian.

Inoceramus hamadae Hayami, n. sp., p. 302, pl. 15, f. 14, Japan.　(If) Callovian.

Inoceramus hashiurensis Hayami, n. sp., p. 303, pl. 15, f. 16, Japan.　(If)？ Callovian.

Inoceramus hookeri Salter, 1865, p. 95, pl. 23, f. 2, Himalaya; Stoliczka, 1875. p. 89. (=*I. everesti* Oppel, 1862, according to Holdhaus, 1913).　(If？) Tithonian.

Inoceramus inconditus Marwick, 1953, p. 93, pl. 12, f. 5, pl. 13, f. 13, New Zealand.　(If or Ig) Bajocian-Bathonian.

Perna inoceramoides Hudleston, 1878, p. 489, England; *Inoceramus inoceramoides* Arkell, 1933, p. 217, pl. 28, f. 1, do.　(If) Oxfordian.

Inoceramus intermedius von Eichwald, 1865, p. 494, pl. 21, f. 7, Tambov. Jurassic？

Inoceramus ischeri Rollier, 1914, p. 414, pl. 25, f. 2, Swiss.　(If) Oxfordian.

Inoceramus (Mytiloceramus) karakuwensis Hayami, n. sp., p. 299, pl., 15 f. 17,

Japan. (Ip) Bajocian.

Inoceramus (s. l.) *kudoi* HAYAMI, n. sp., p. 312, pl. 16, f. 9, pl. 18, f. 3-4 Japan. (Io) Aalenian.

Inoceramus laevigatus MÜNSTER in GOLDFUSS, 1836, p. 111, pl. 109, f. 6, Germany; GREPPIN, 1870, p. 29, Swiss; ROLLIER, 1914, p. 420, listed; Wetzel, 1950, p. 108, Germany. (If) Aalenian-? Bathonian.

Parainoceramus lenaensis VORONETZ, 1936, p. 34, pl. 1, f. 5, 7, 9, North Siberia. (P) Upper Triassic.

Inoceramus lucifer von EICHWALD, 1871, p. 194, pl. 18, f. 5-7, Alaska; IMLAY, 1955, p. 86, pl. 8, f. 1, 5-10, Alaska; FREBOLD, 1958, p. 15, pl. 14, f. 1, 2, pl. 15, f. 2, pl. 16, f. 1, 2, Prince Patrick; cf. HAYAMI, 1960, p. 304, pl. 16, f. 1. (Il) Bajocian.

Parainoceramus lunaris HAYAMI, n. sp., p. 295, pl. 15, f. 1, Japan. (P) Pliensbachian.

Inoceramus maedae HAYAMI, n. sp., p. 308, pl. 17, f. 1-3, pl. 16, f. 1-2, pl. 14, f. 7, Japan. (In) ? Oxfordian.

Parainoceramus matsumotoi HAYAMI, n. sp., p. 296, pl. 15, f. 2-8, Japan; cf., HAYAMI, 1960, p. 297, pl. 15, f. 9, do.; ex gr., HAYAMI, 1960, p. 298, pl. 15, f. 10, do. (P) Toarcian.

Myoconcha ? *meyrati* FISCHER-OOSTER, 1869, p. 74, 98, pl. 3, f. 12, Germany; ROLLIER, 1914, p. 417, listed. (*Inoceramus* ?) Rhaetic.

Inoceramus morii HAYAMI, 1959, p. 59, pl. 5, f. 12-14, Japan; HAYAMI, 1960, p. 300, pl. 15, f. 11-12, do. (If) Bajocian.

Inoceramus ? *naganoensis* HAYAMI, n. sp., p. 315, pl. 16, f. 6, Japan. (*Inoceramus* ?) Callovian or Oxfordian.

Parainoceramus nikolaiewi VORONETZ, 1936, p. 34, pl. 1, f. 4, 6, 12, 13, North Siberia; *Inoceramus* ? *nikolaiewi*, KIPARISOVA, 1938, p. 45, pl. 6, f. 16, do. (P) Upper Triassic.

Inoceramus nitescens ARKELL, 1933, p. 218, pl. 28, f. 2, 3, England; cf., HAYAMI, 1960, p. 302, pl. 15, f. 15, Japan. (If) ? Callovian-Oxfordian.

Inoceramus nobilis MÜNSTER in GOLDFUSS, 1836, p. 109, pl. 109, f. 4, Germany. Lias (Cretaceous according to BOEHM, 1911, p. 400).

Inoceramus obliquiformis McLEARN, 1924, p. 41, pl. 3, f. 9, FREBOLD 1957, p. 21), Alberta. (Ig ?) Callovian.

Inoceramus obliquus MORRIS and LYCETT, 1853, p. 24, pl. 6, f. 12, England; WOODWARD, 1887, p. 313, do.; ROLLIER, 1914, p. 422, listed; QUENSTEDT, 1856, p. 355, Germany. (If) Bajocian-Bathonian.

Inoceramus ogurai KOBAYASHI, 1926, p. 7, pl. 11, f. 3, Japan; HAYAMI, 1960, p. 406, pl. 16, f. 2, do. (Ir) Callovian or thereabout.

Inoceramus oosteri FAVRE, 1876, p. 64, pl. 6, f. 2, Alps. (=*I. bruneri* OOSTER). (If or In) Oxfordian.

Inoceramus pernoides GOLDFUSS, 1836, p. 109, pl. 109, f. 3, Germany. (non *I. pernoides* ETHERIDGE, 1872). (=*I. ventricosus* SOWERBY, 1825, according to ROLLIER, 1914). (P) Pliensbachian.

Gervillia pinnaeformis DUNKER, 1851, p. 179, pl. 25, f. 10-11, Germany; *Inoceramus*

pinnaeformis BRAUNS, 1871, p. 361, do., PHILIPPI, 1897, p. 437, do., ROLLIER, 1914, p. 416, listed. (P) Hettangian.

Inoceramus polyplocus ROEMER, 1857, p. 624, Germany (=*I. dubius* GOLDFUSS, 1836, non SOWERBY, 1826); BENECK, 1905, p. 145, pl. 8, f. 1–5, Germany; ROLLIER, 1914, p. 421, listed; SCHMIDTILL, 1926, p. 16, pl. 4, f. 3, Germany; cf. HORWITZ, 1937, p. 212, Poland; ex gr., PČELINČEV, 1937, p. 52, pl. 4, f. 2, Caucasus. (Ip) Aalenian-Bajocian.

Inoceramus porrectus VON EICHWALD, 1871, p. 191, pl. 19, f. 1, 2, Alaska. (Io) Jurassic (according to MARTIN, 1926).

Mytilus psilonoti QUENSTEDT, 1856, p. 48, pl. 4, f. 14, Germany (?=*I. pinnaeformis* DUNKER, 1851). (P ?) Hettangian.

Inoceramus quenstedti PČELINČEV, 1933, p. 13, pl. 1, f. 6; pl. 2, f. 2, Caucasus; PČELINČEV, 1937, p. 50, 70, pl. 4, f. 3–6, Caucasus; aff., BODYLEVSKI and SHULGINA, 1958, p. 60, Yenisei. (If) Aalenian.

Inoceramus retrorsus KEYSERLING, 1848, p. 12, pl. 4, f. 4, 5, Siberia; LAHUSEN, 1886, p. 3, pl. 1, f. 1, Lena; SPATH, 1932, p. 110, text-fig. 8, Greenland; VORONETZ, 1936, p. 22, pl. 1, f. 1; pl. 3, f. 38, North Siberia; DONOVAN, 1953, p. 70, Greenland; ex gr., VORONETZ, 1936, p. 23, pl. 3, f. 37, North Siberia. (Ir) Bathonian-Callovian.

Posidonia revelata KEYSERLING, 1846, p. 302, pl. 14, f. 12–15, Petchora. (*Inoceramya* ?) Jurassic.

Inoceramus rostratus GOLDFUSS, 1836, p. 110, pl. 115, f. 3, Germany; ROLLIER, 1914, p. 418, listed. (If ?) Pliensbachian.

Inoceramus secundus MÉRIAN, 1853; MÜLLER, 1862, p. 56; MOESCH, 1867, p. 73; GREPPIN, 1899, p. 109, pl. 15, f. 1, Swiss; ROLLIER, 1914, p. 417, listed. (Ip) Bajocian.

Inoceramus stoliczkai HOLDHAUS, 1913, p. 418, pl. 98, f. 10–11, Himalaya. (Io) Tithonian.

Inoceramus subhaasti WANDEL, 1936, p. 469, pl. 15, f. 1, 2, pl. 16, f. 5, pl. 18, f. 1–3, text-fig. 3, Sulu (including *lateplicata*, *intermedia* and *denseplicata* as varieties); AVIAS, 1953, p. 169, pl. 23, f. 3, New Caledonia; cf., ROUTHIER, 1953, p. 56, pl. 2, f. 9, New Caledonia. (Ig) Oxfordian.

Inoceramus substriatus MÜNSTER in GOLDFUSS, 1836, p. 108, pl. 109, f. 2, pl. 115, f. 1, Germany; ROEMER, 1836, p. 83, do.; OPPEL, 1853, p. 81, do.; FUCINI, 1893, p. 88, pl. 5, f. 10–11, Italy; ROLLIER, 1914, p. 418, listed; *Parainoceramus substriatus*, COX, 1954, p. 47, Germany; cf., BEHRENDSEEN, 1891, p. 387, Argentina. (P) Pliensbachian.

Inoceramus sularum BOEHM, 1907, p. 70, pl. 11, f. 1, Sulu; cf., HOLDHAUS, 1913, p. 420, text-fig., Himalaya. (Ig) Oxfordian-Tithonian.

Inoceramus taliabuticus BOEHM, 1907, p. 69, pl. 11, f. 2, Sulu. (Ig) Oxfordian.

Perna thermarum MOESCH, 1867, p. 308, pl. 3, f. 2, Swiss. (P) Lias.

Inoceramus undulatus ZIETEN, 1830, pl. 72, fig. 7, Germany; OOSTER, 1869, p. 37, pl. 12, f. 6, Alps; DUMORTIER, 1874, p. 185, France; ROLLIER, 1914, p. 420, listed. (non *I. undulatus* MANTELL). (If ?) Toarcian.

Inoceramus utanoensis KOBAYASHI, 1926, p. 7, pl. 11, f. 1–2, Japan; HAYAMI, 1960,

p. 305, pl. 16, f. 3–5, do. (Ir) Callovian or thereabout.

Crenatula ventricosa SOWERBY, 1825, p. 64, pl. 443, 2 figs., England; *Inoceramus ventricosus* DUMORTIER, 1869, p. 134, pl. 21, f. 5–6, France; ROLLIER, 1914, p. 417, listed; *Parainoceramus ventricosus,* COX, 1954, p. 47, England. (P) Pliensbachian.

Inoceramus weissmanni OPPEL, 1856–1858, p. 101, Germany; MÖSCH, 1867, p. 47, 49; ROLLIER, 1914, p. 46. (P ?) Hettangian.

Inoceramus sp., ZIETEN, 1830, p. 96, pl. 72, f. 5, Germany. Lias.

Inoceramus sp., EVEREST, 1863, pl. 2, f. 29, Himalaya (→*Inoceramus everesti* OPPEL). (Ig ?) Tithonian.

Inoceramus sp., KRAUSE, 1896, p. 157, Borneo. Lias.

Inoceramus sp., NEWTON and TEALL, 1898, p. 650, pl. 29, f. 4, Franz Joseph Land. Jurassic.

Inoceramus sp., POMPECKJ, 1901, p. 271, Alaska. Jurassic.

Inoceramus sp., HOLDHAUS, 1913, p. 421, Himalaya. Tithonian.

Inoceramus sp., TILMANN, 1917, p. 674, Peru. ? Sinemurian.

Inoceramus sp., SCHLÜTTER, 1928, p. 59, New Guinea. Jurassic.

Inoceramus sp., SPATH, 1932, p. 112, pl. 4, f. 12, Greenland. (Ir ?) Bathonian-Callovian.

Inoceramus sp., WANDEL, 1936, p. 475, Misol. Oxfordian.

Inoceramus sp., COX, 1940, p. 127, pl. 7, f. 8, Cutch. (If) Oxfordian.

Inoceramus sp., GARDET and GÉRARD, 1946, p. 39, pl. 8, f. 5, Morocoo. (If ?) Bajocian.

Inoceramus sp., AVIAS, 1953, p. 169, pl. 23, f. 6, New Caledonia. (Ig) Oxfordian.

Inoceramus sp., AVIAS, 1953, p. 170, pl. 23, f. 8, New Caledonia. (Ig) Oxfordian.

Inoceramus ? sp., AVIAS, 1953, p. 151, pl. 23, f. 5, New Caledonia. (P ?) Hettangian.

Inoceramus sp., ROUTHIER, 1953, p. 56, pl. 2, f. 7, New Caledonia. (Ig) Upper Jurassic.

Inoceramus sp., ROUTHIER, 1953, p. 56, pl. 2, f. 10, New Caledonia. (Ig) Upper Jurassic.

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Appendix

Occurrences of an Isognomonid in the Japanese Permian

Genus *Isognomon* SOLANDER, 1786

" *Isognomon* " n. sp. indet.

Text-figure 6.

Description :—Shell medium, linguiform, nearly as long as high, not strongly inflated right internal mould, PM 3612, 33.0 mm. long; 29.5+mm. high; 5.5 mm. thick; obliquity ca. 45 degrees); anterior wing small, triangular, clearly demarcated from remaining surface; anterior margin deeply sinuated at median part; apical angle about 50 degrees; postero-dorsal part flattened but not auriculate; hinge-line moderate in length, occupying about three-fifths of shell-length; umbo terminal, pointed anteriorly; hinge nearly edentulous except a weak posterior lateral tooth which runs subparallel to posterior hinge-margin; ligament area moderate in breadth, provided with five distinct pits of *Isognomon*-type byssal gape observable in front of anterior wing; surface striated with fine concentric lamellae besides numerous growth-lines.

Observation and comparison :—Represented only by a specimen of right valve composed of internal and external moulds. Though such a distinct anterior wing is unknown in *Isognomon*, the weakness of dentition, developed multivincular ligament structure, byssal gaping and other principal characters are more similar to Mesozoic and Recent *Isognomon* (s. s.) than other genera. Some species of *Cuneigervillia* Cox, 1954, from the Lias resembles this in the general outline, but byssal gape and anterior wing are absent in that genus. This is anyhow different from *Bakevellia*, since coeval *Bakevellia* seems to be characterized by the smaller dimensions, smaller number of ligament pits, distinct cardinal teeth and more *Pteria*-like outline (developed posterior wing). This form, though I do not give it a name, may be the first
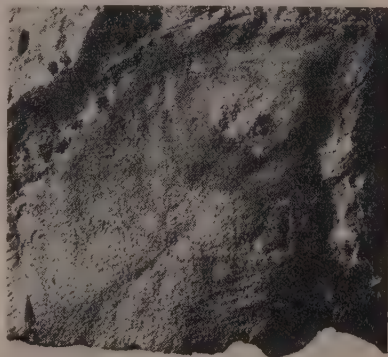
Text-figure 6. Right in. mould of " *Isognomon* " n. sp. (PM 3612) from the Middle Permian Kanokura group at Omotematsukawa, Kesennuma City, ×1.5. KOJIMA coll. Numerous holes are the external moulds of *Parafusulina matsubashi* FUJIMOTO.

Palaeozoic isognomonid, and bears importance for the phylogeny of the Isognomonidae.

Occurrence:—Rare in the *Parafusulina matsubaishi* FUJIMOTO bearing sandstone of the middle Kanokura series (Kamiyatsuse formation by SHIIDA, 1940) at Omotematsukawa, Kesennuma City, Miyagi Prefecture. Middle Permian. Collected by Mr. Keiji KOJIMA whom I acknowledge for his donation of the material.

Postscript

1. After the manuscript of this paper was completed, I read C. A. FLEMING's paper (Upper Jurassic Fossils and Hydrocarbon Traces from the Cheviot Hills, North Canterbury. *N. Z. Jour. Geol. Geophysics, Vol. 1, No. 2, 1958*), where he described *Inoceramus* n. sp. A ? aff. *everesti* OPPEL and *I.* n. sp. B ? aff. *gracilis* HOLDHAUS from the Tithonian of South New Zealand and referred another species to *Anopaea* VON EICHWALD, 1861. *Anopaea* was originally founded on *Inoceramus lobatus* AUERBACH and FREARS, 1846, non MÜNSTER in GOLDFUSS, 1836, from "the Neocomian of Russia", which has a rib-like internal tooth below the beak of left valve and a deep "lunule". Some Uppermost Jurassic inoceramids from European Russia, Spiti and Taliabu, which were assigned to *Anopaea* by BOEHM (1904) and FLEMING, have oval outline and developed anterior part with excavated byssal sinus, and may be generically distinct from typical *Inoceramus*. But further informations on the stratigraphical occurrence and diagnostic characters of the type-species are desirable for the application of the generic name.

2. Recently VORONETZ and some other Russian authors described and listed many inoceramids, such as *Inoceramus formosulus, I. ussuriensis, I. skorochodi, I. rhomboideus, I. porrectiformis, I. aequicostatus, I. subambiguus* and *I. lucifer* from the Aalenian of Eastern Siberia and Sichota Alin Mountains. Though I cannot at present refer to their detailed descriptions and illustrations, their precise comparison with Japanese inoceramids seems necessary to promote the biostratigraphy and palaeobiogeography.

(June 23, 1960)

3. In the midst of printing of this paper, I could recognize the specific characters of some Siberian inoceramids through the courtesy of Dr. L. D. KIPARISOVA who kindly sent me a book, entitled "New species of palaeo-plants and invertebrates in USSR, Vol. 2. *Moscow*, 1960". So far as judged from the illustrations, *Inoceramus subambiguus* PČELINCEVA, 1960, from the Aalenian of Okhotsk region is, if not identical with, very close to *Inoceramus morii* HAYAMI, 1959, and *Inoceramus kystatymensis* KOSCHELKINA, 1960, from the Bathonian of Lena region is hardly distinguishable from *Inoceramus utanoensis* KOBAYASHI, 1926. *Inoceramus menneri* KOSCHELKINA, 1960, from the Bajocian of Lena is referable to the group of *I. lucifer* in my classification. (July 19, 1960)

I. HAYAMI

Jurassic Inoceramids in Japan.

Plate XV

Explanation of Plate XV

I. Hayami

Jurassic Inoceramids in Japan.

Plate XVI

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Explanation of Plate XVI

I. HAYAMI

Jurassic Inoceramids in Japan.

Plate XVII

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Explanation of Plate XVII

  Figs. 1a-b. Right internal mould (MM 9077), paratype, ×1, and gypsum cast from the same external mould, ×1. Malm at Mitarai, Shokawa, Gifu Pref. MAEDA coll.

  Figs. 2a-b. Left valve (MM 9078), paratype, ×1, and its upper view, ×1. Do. MREDA coll.

  Fig. 3a. Right internal mould (MM 9076), holotype, ×3/4. Do. MAEDA coll.

  Fig. 3b. Vertical section of the prismatic calcite layer of the holotype, prepared from the ventral part of the shell adhered to the external mould, ×22, (under open nicol).

  Fig. 3c. Horizontal section of the prismatic calcite layer of the holotype, prepared from the middle part of the shell adhered to the external mould, ×66, (under open nicol).
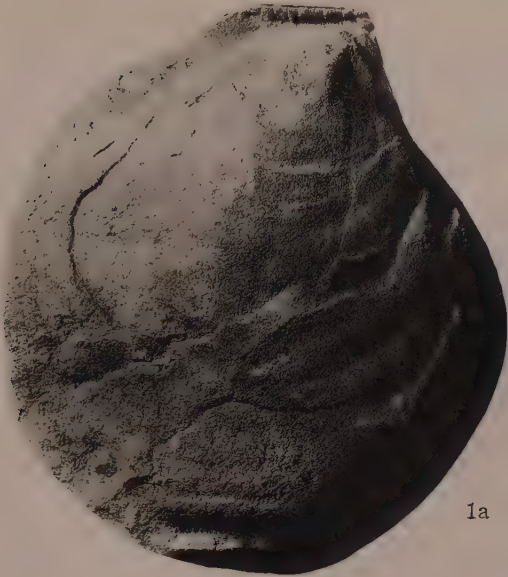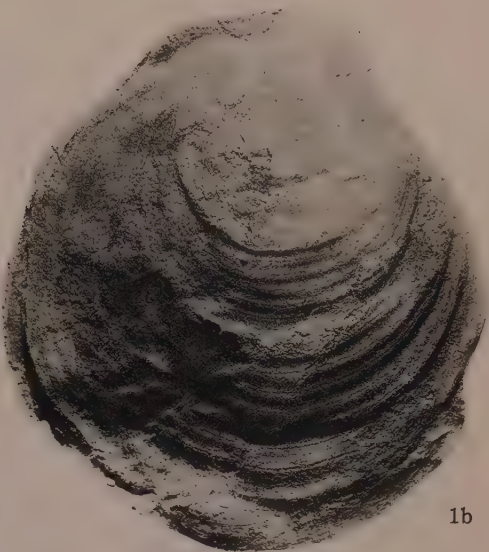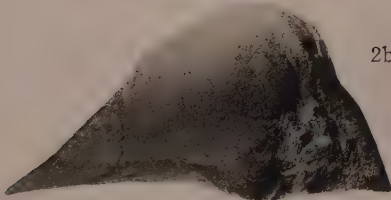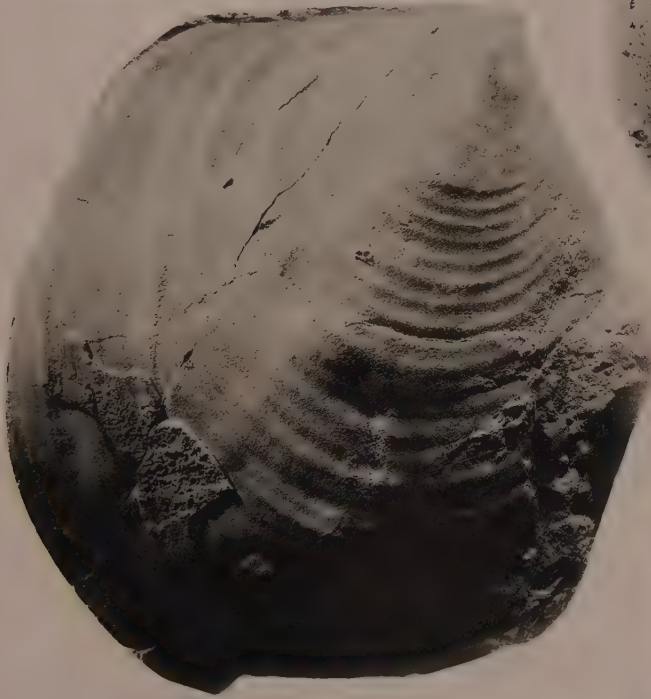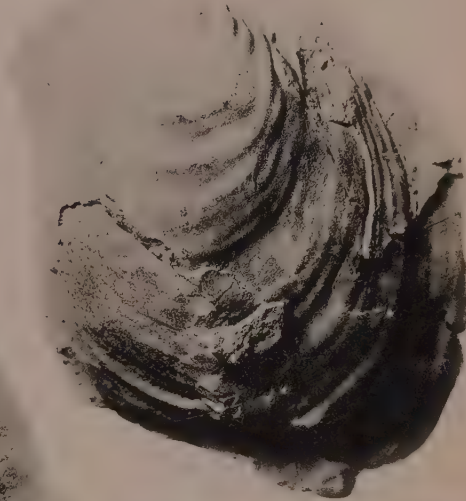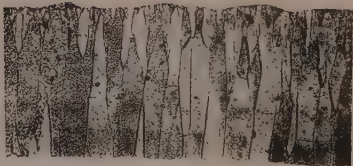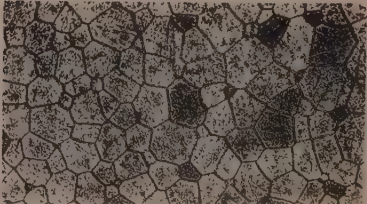
I. HAYAMI

Jurassic Inoceramids in Japan.

Plate XVIII

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Explanation of Plate XVIII

All specimens illustrated in this paper are kept in the Geological Institue, University of Tokyo
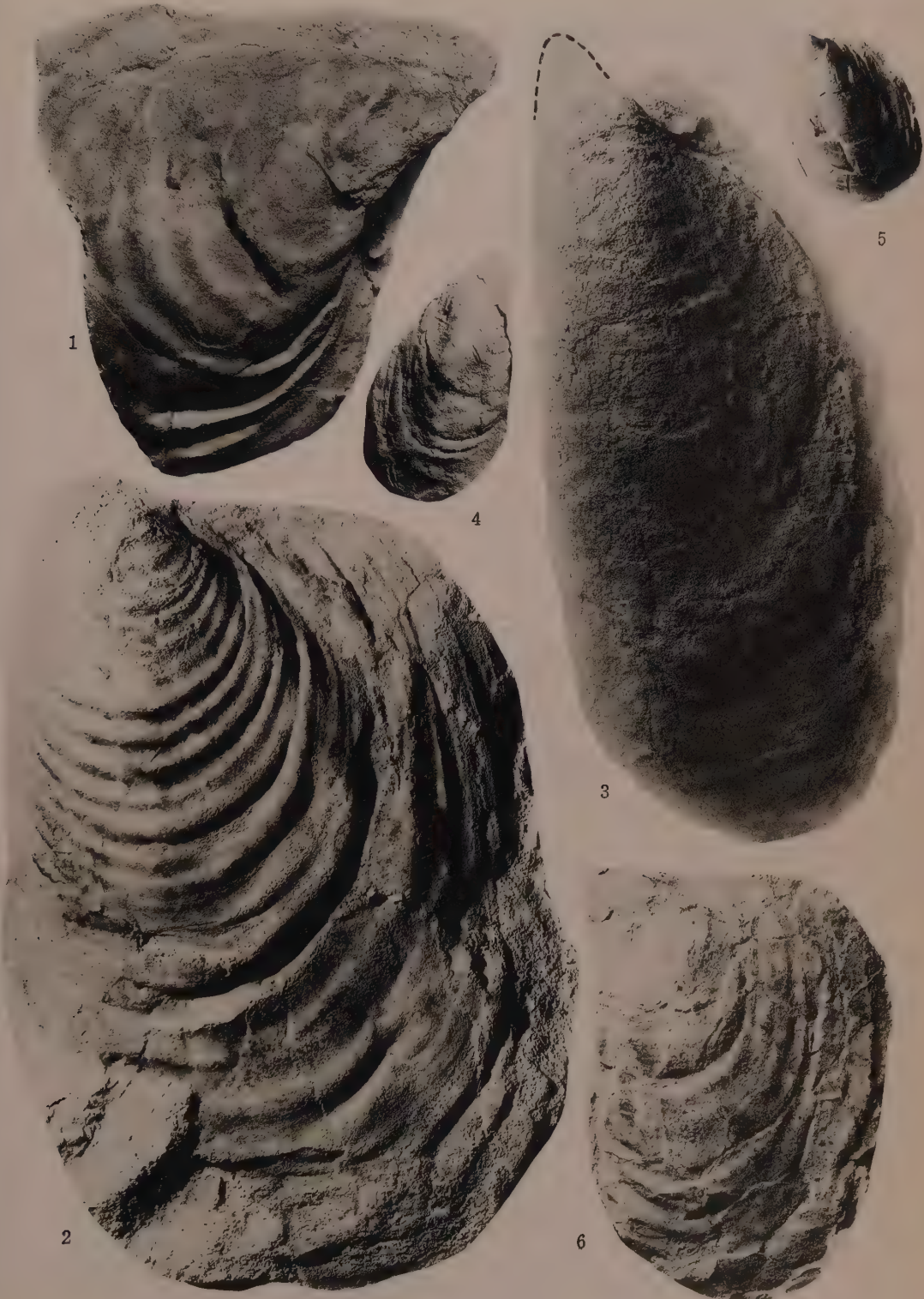
THE CAMBRO-ORDOVICIAN FORMATIONS AND FAUNAS OF SOUTH KOREA, PART VII, PALAEONTOLOGY VI.

Supplement to the Cambrian Faunas of the Tsuibon Zone with Notes on some Trilobites Genera and Families

By

Teiichi Kobayashi

With Plates XIX–XXI

Contents

Introductory Notes

This is a supplement to the Cambrian Faunas of South Korean in the Tsuibon Zone and its adjacence which is made with IWAYA and SHIRAKI's collections. They contain 17 new species beside new occurrences of known species in South Korea. Now the *Redlichia* and *Bailiella* zones were ascertained to exist in this area.

SHIRAKI's collections were made many years ago by his assistants in two areas on the southern flank of the Hakuunsan syncline. Fossils marked with Dai were obtained from the vicinity of Taehyon-ni which is located to the southwest of Tongjom-ni i. e. Doten-ri. The *Redlichia* slate at Dai 1 belongs to the southwestern prolongation of the Beiho s'ate in the basal part of Doten section.

Fossils marked with Sho were procured from the Ch'ongori area on the west side of the Hambaeksan or Kampakusan fault and on the north side of Mt. Taipaik. The collection is of great value because it contains many new fossils. The *Bailiella* green slate which was presumably collected from the basel part of the Taiki formation indicates a new fossil zone in South Korea.

In his geological survey in 1939-40 Yoshiyuki IWAYA has discovered a few Upper Cambrian trilobites in boulders at Tokoni. This find bears importance especially because the locality lies in the so-called triangle of Uiimgil, i. e. Girinkitsu where fossils are exceedingly rare.

The relation of the zonation in the Tsuibon zone to the general classification of the Cambrian system of Eastern Asia is as follows:

Kasetsu group	*Eoorthis* zone *Dictyites* zone	·············Fengshanian
	Kaolishania zone	···········Daizanian
	Chuangia zone *Prochuangia* zone	···········Changshanian
Seison slate	*Drepanura* zone *Stephanocare* zone	···········Kushanian
Taiki group	*Solenoparia* zone *Megagraulos* zone *Bailiella* zone	Changhian — Taitzuan / Tangshihan / (or Mapanian)
Beiho slate	*Elrathia* zone *Mapania* zone	···········Shihchiaoan
	Redlichia zone	···········Misakian
Sohsan quartzite	No fossil	···········Bunsanrian

(Chaumitian; Fuchouan; Mantoan brackets at right)

On this occasion Cambrian trilobites genera and families are discussed in some detail, paying special attention to Asiatic genera and Eastern Asiatic species. Many selected trilobites are tentatively restored and shown in text-figures. The restoration was however, not a facile task, especially when the specimen is imprefect, the illustration obscure, or the description brief. Naturally, those ill-restored ones must be corrected in future.

My cordial thanks are due to the collectors of these fossils, to Mr. Shiro

SUZUKI who has drawn the text-figures, and to Messer Zenji KONISHI and Kei-ichi TAKEUCHI for their assistance of reading some references in Russian.

Localties and Formations

Dai 1 (大 1): Black slate in the lower Beiho slate formation at a point between Ichom-ni and Taehyon-ni, Soch'on-myŏn, Ponghwa-kun, Kyongsang-bukto (慶尙北道奉化郡小川面梨店里・大峴里間).

> *Redlichia saitoi* LU

Sho (所) 1-20: All in Sangjang-myŏn, Samch'ok-kun, Kangwŏn-do (江原道三陟郡上長面).

Sho 1: West side of a trail, 750 m. south of Sodo-ri (所道里).
Seison slate of the Kushan stage.

> *Drepanura premesnili* BERGERON
> *Pseudagnostus douvillei* (BERGERON)
> *Myona flabelliformis* KOBAYASHI

Lower Kasetzu formation; *Chuangia* zone.

> *Hypseloconus coreanicus* KOBAYASHI, new species
> *Pseudagnostus chinensis* (DAMES)
> *Kabutocrania fossula* KOBAYASHI, new genus and species
> *Chuangia taihakuensis* KOBAYASHI

Upper Kasetsu formation; *Dictyites* zone.

> *Obolus taianensis* SUN
> *Lingulella kayseri* SUN
> *Prolloydia orientalis* KOBAYASHI, new gen. and sp.
> *Mareda mukazegata* KOBAYASHI
> *Platysaukia eurycephala* KOBAYASHI, new gen. and sp.
> *Quadraticephalus quadratus* KOBAYASHI
> *Quadraticephalus coreanicus* KOBAYASHI, new species

Sho 2: Western slope, 750 m. south of Sodo-ri.
Lower Kasetsu formation; *Chuangia* zone.

> *Pseudagnostus chinensis* (DAMES)

Middle Kasetsu formation, red sandstone; *Kaolishania* zone.

> *Lingulella kayseri* SUN
> *Lingulepis shamojiformis* KOBAYASHI, new species
> *Lingulepis* (?) sp.

Upper Kasetsu formation; *Dictyites* zone.

> *Palaeostrophia orthis* (WALCOTT)
> *Hyolithes imbicatus* KOBAYASHI, new species
> *Geragnostella cambria* KOBAYASHI, new species
> *Pagodia coreanica* KOBAYASHI, new species
> *Mimana euryrachis* KOBAYASHI
> *Megamansuyia glabra* (ENDO)
> *Mansuyia trigonalis* KOBAYASHI, new species
> *Tsinania canens* (WALCOTT)
> *Saukiella* sp. (pygidium)

Sho 3:   About 50 m. southwest of Sho 2; *Chuangia* zone.

Billingsella pumpellyi Walcott
Chuangia sp.
Lioparia coniculus Kobayashi, new species

Sho 4:   350 m. west southwest of Sho 2.
Middle Kasetsu formation; *Kaolishania* zone.

Pseudagnostus cyclopygeformis (Sun)
Kaolishania granulosa Kobayashi
Shirakiella laticonvexa Kobayashi

Upper Kasetsu formation; *Dictyites* zone.

Obolus taianensis Sun
Palaeostrophia orthis (Walcott)
Tsininia canens (Walcott)
Quadraticephalus coreanicus Kobayashi

Sho 5:   South side between Sodo-ri and Hyŏl-li (穴里); *Dictyites* zone.

Eoorthis shakuotunensis Sun
Dictyites dictys (Walcott)
Tellerina coreanica Kobayashi

Sho 6:   North side of the same place as Sho 5; *Dictyites* zone.
Pygidium, gen. et sp. indt.

Sho 10:   450 m. west of Tanggok (堂谷); *Solenoparia* zone.

Kootenia sp.
Solenoparia laevis Kobayashi
Eymekops carinata Kobayashi, new species
Eymekops expansus (Kobayashi)

Sho 11:   200 m. east of Sho 10; *Solenoparia* zone.

Dorypyge taihakuensis Kobayashi
Manchuriella convexa Kobayashi

Sho 14:   750 m. southeast of Tanggok; *Solenoparia* zone.

Dorypyge cfr. *taihakuensis* Kobayashi
Grandioculus sp.

Sho 15:   900 m. southeast of Tanggok, Kushan stage.

Pseudagnostus douvillei (Bergeron)
Damesella paronai Airaghi
Drepanura premesnili Bergeron

Sho 16:   South and East of Tanggok.
(a)   Beiho slate; *Bailiella* zone, (a valley south of Tanggok).

Bailiella angusta Kobayashi, new species

(b)   Kushan slate, (200 m. east of Sho 15).

Drepanura premesnili Bergeron

(c)   *Kaolishania* zone, (east slope, 300 m. south of Tanggok).

Lingulella kayseri Sun
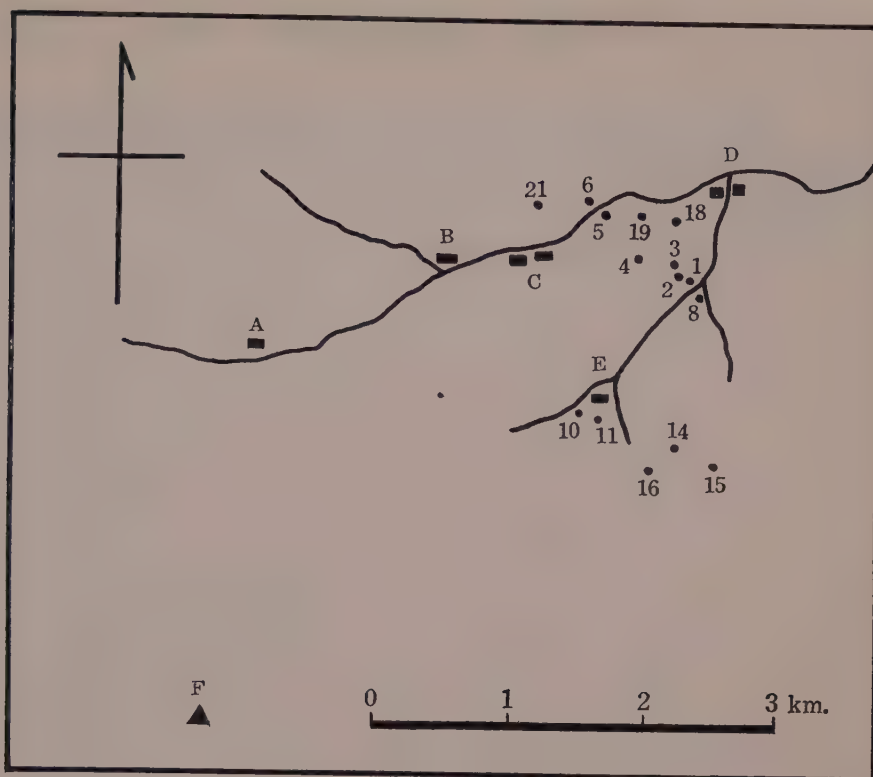
Fossil Localities of Ch'ongori District

A.   Ch'ongo-ri, 程巨里   B.   Hyol-li, 穴里
C.   Chango-ri, 長渠里   D.   Sodo-ri, 所道里
E.   Tanggok, 堂谷   F.   Mt. Taipaik, 大白山

Pseudagnostus cyclopygeformis (SUN)
Kaolishania granulosa KOBAYASHI
(?) *Kaolishaniella transita* SUN
Tingocephalus magnus KOBAYASHI, new species
Shirakiella laticonvexa KOBAYASHI
Shirakiella elongata KOBAYASHI
Shirakiella (?) sp. (pygidium)
Megamansuyia glabra (ENDO)

Sho 18:   350 m. southwest of Sodo-ri; *Dictyites* zone.

Quadraticephalus coreanicus KOBAYASHI
Tsinania ceres (WALCOTT)

Sho 19:   400 m. west of Sho 18; *Dictyites* zone.

Geragnostus obsoletus KOBAYASHI
Koldinioidea sp.
Haniwa quadrata KOBAYASHI
Quadraticephalus coreanicus KOBAYASHI
Quadraticephalus coreanicus (immature form)
(?) *Tellerina coreanica* KOBAYASHI
Saukia sp.

Sho 21: 300 m. north of Chango-ri (長渠里) and 1 km. northeast of Hyŏl-li; *Dictyites* zone. (?)

"*Calvinella*" sp. indt.

F 18. Boulder at Tokŏni (塔巨里), Shindong-myŏn, Chŏngsŏn-gun, Kangwŏn-do. (新東西面旌善郡江原道)

Dictyites depressa Kobayashi
Quadraticephalus manchuricus Kobayashi

Description of Fossils

In this paper are described 42 species of Cambrian fossils including 3 forms specifically indeterminable.   Beside three new subfamilies, i.e. Paramenomoninae, Menocephalitinae, and Liopariinae, 8 new genera and 20 new species are proposed in this paper as below:

New genera

Kabutocrania

Iranochuangia

Prolloydia

Paramenocephalites

Cyclolorenzella

Latilorenzella

Taipaikia

Platysaukia

New species

Lingulepis shamojiformis

Hypseloconus coreanicus

Hyolithes imbricatus

Geragnostus obsoletus

Geragnostella cambria

Kaolishania (?) *latiura*

Tingocephalus magnus

Kabutocrania fossula

Iranochuangia narghunensis

Mansuyia hopeiensis

Mansuyia trigonalis

Prolloydia orientalis

Pagodia coreanica

Liasania convergens

Bailiella angusta

Solenoparia laevis

Lioparia conciculus

Eymekops carinata

Quadraticephalus coreanicus

Platysaukia euryrachis

New observations which I made on immature forms of *Bailiella lantonoisi* are here added.   The Dorypygidae, Damesellidae, Leiostegiidae, Pagodiidae, Solenopleuridae, Acrocephalitinae, Agraulinae, Liopariinae, Anomocaridae, Tsinanidae and Ptychaspidae are discussed in some length.

Phylum Brachiopoda

Class Inarticulata

Order Atremata BEECHER, 1891

Family Obolidae KING, 1846

Genus *Obolus* EICHWALD, 1829

Obolus taianensis SUN

Plate XIX, Figure 5.

1935. *Obolus taianensis* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 60, pl. 14, fig. 22. See for previous synonymic references.
1939. *Obolus taianensis* ENDO, *Jubilee Publ. Comm. Prof. Yabe, 60th Birthday, Vol. 1*, p. 3, pl. 1, figs. 3–4.

Occurrence:—*Dictyites* zone at Sho 1 and Sho 4; common in late and middle Upper Cambrian in Korea, South Manchuria and North China.

Genus *Lingulella* SALTER, 1866

Lingulella kayseri SUN

Plate XIX, Figures 3 and 3a.

1924. *Lingulella kayseri* SUN, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 22, pl. 2, figs. 10a–c.
1931. *Lingulella kayseri* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 8*, p. 155, pl. 21, fig. 9.
1933. *Lingulella kayseri* KOBAYASHI, *Ibid. Vol. 11*, p. 93.
1937. *Lingulella pingchouensis* RESSER and ENDO, *Manchurian Sci. Mus. Bull. 2*, p. 125, pl. 55, figs. 5–8.
1937. *Lingulella kayseri* ENDO, *Ibid. Vol. 2*, p. 308, pl. 68, figs. 3–5.

L. pingchouensis is placed in this specific circle because of the statement that "Surface marked by the fine concentric striae and rather coarse lines of growth which are crossed by radial lines." This species is well characterized by roundly rectangular outline as well as reticulate ornamentation. As noted already, the outline and especially the ratio of the breadth to the length of the shell is variable to some extent.

The extraordinarily broad form illustrated in 1931 is, I think, appropriate to be distinguished from the others as a distinct subspecies, *latissima*.

Occurrence:—*Dictyites* zone at Sho 1 and *Kaolishania* zone at Sho 2, common in the late and middle Upper Cambrian of North China, South Manchuria and North and South Korea.

Genus *Lingulepis* HALL, 1863

Lingulepis shamojiformis KOBAYASHI, new species

Plate XIX, Figure 2.

Description:—Ventral valve moderately convex, nearly as long as broad, semicircular in anterior, triangular in posterior and a little acuminate at beak.

Comparison:—Although the very beak is broken off, it is certainly not so far protruded as in *Lingula pinnaformis* OWEN, the type-species of this genus. The outline is broader than any of the genus in WALCOTT's monograph (1912).

Occurrence:—*Kaolishania* zone at 2.   This is the fisrt to find this genus in Eastern Asia.

<center>*Lingulepis* (?) sp.</center>

<center>Plate XIX, Figure 4.</center>

This is different from the preceding in the broader and more rounded outline.   Though imperfectly preserved, its beak is evidently more acuminate than that of the preceding.   It is a remarkable fact that these two Asiatic species are both much broader than American ones of *Lingulepis*.

Occurrence:—Same as the preceding.

<center>Class Articulata</center>

<center>Order Neotremata BEECHER, 1891</center>

<center>Family Huenellidae SCHUCHERT and COOPER, 1936</center>

<center>Genus *Palaeostrophia* ULRICH and COOPER, 1936</center>

<center>*Palaeostrophia orthia* (WALCOTT)</center>

<center>Plate XIX, Figure 1.</center>

1905. *Syntrophia orthia* WALCOTT, *Proc. U. S. Nat. Mus. Vol. 29*, p. 11.
1912. *Syntrophia orthia* WALCOTT, *U. S. Geol. Surv. Monogr. 51*, p. 803, pl. 104, figs, 4, 4a–b.
1913. *Syntrophia orthia* WALCOTT, *Research in China, Vol. 3*, p. 54, pl. 85, pl. 5, figs. 1, 1a–b.
1924. *Syntrophia orthia* SUN, *Pal. Sinica, Ser. B. Vol. 1, Fasc. 1*, p. 25, pl. 1, figs. 14a–b.
1936. *Palaeostrophia orthia* ULRICH and COOPER, *Jour. Pal. Vol. 10*, p. 627.
1937. *Palaeostrophia orthia* ENDO *Manchurian Sci. Mus. 1*, p. 313, pl. 67, fig. 28.
1938. *Palaeostrophia orthia* ULRICH and COOPER, *Geol. Soc. Am. Sp. Pap. No. 13*, p. 196.

This is a well known species wide spread in North China and South Manchuria in the *Tsinania* and *Kaolishania* zones, but this is the first instance to be reported from South Korea.   It can easily be distinguised from *Palaeostrophia recta* WANG, 1956, from the Upper Cambrian of Kiangsu by its sub-triangular outline.   The subrectangular outline of the Kiangsu form is not diagnostic of *Palaeostrophia*, but rather reminds one of *Plectostrophia* ULRICH and COOPER.

Occurrence:—*Tsinania* zone at Sho 2 and Sho 6; Upper Cambrian in Shantung and Liaoning.

<center>Phylum Mollusca</center>

<center>Class Gastropoda</center>

<center>Order Monoplacophora</center>

<center>Family Hypseloconidae KNIGHT, 1952</center>

Genus *Hypseloconus* BERKEY, 1898

Hypseloconus coreanicus KOBAYASHI, new species

Plate XIX, Figures 9a–b.

Description :—Breviconic cyrtocone, lenticular in cross section, subangulated on lateral sides; apex broken off; apical angle measures 25 degrees in one way and 40 degrees in the other. Test thick; no surface sculpture.

Observation :—The specimen is 92 mm. long The major and minor diameter of the adoral section are 9 mm. and 6.2 mm. respectively, One of the lateral, peripheries is deformed. The shell convexity in lateral view is much greater on the inner than the outer wall.

Occurrence :—*Chuangia* zone at Sho 1. This is the first occurrence of *Hypselconus* in Eastern Asia.

Incerta Sedis

Family Hyolithellidae

Genus *Hyolithes* EICHWALD

Hyolithes imbricatus KOBAYASHI, new species

Plate XIX, Figures 10a–b.

Shell small, longiconic and subelliptical in cross section. The specimen is 16 mm. long; apical angle 10 degrees; apex broken off; longer diameter measures 1.5 mm. at the broken end; one side of the shell slightly arcuate and concave; the other side a little more arcuate and convex; angle between the two margins reduced to 5 degrees at the adoral end of the specimen where the major and minor diameter measures 3.7 mm. and 2.2 mm. respectively; convex margin distinctly carinate on the dorsal side.

Through a close observation growth lines are found gently slant from the concave to the convex side; shell repeats to form steps at growth lines, the aspect suggesting the invagination of growth segments. The peripheral carination appears to have been secondarily strengthened.

Occurrence :—*Dictyites* zone at She 2, accompanied by *Haniwa* in the same specimen.

Phylum Arthropoda

Class Trilobita

Order Agnostida KOBAYASHI, 1935

Family Pseudagnostidae WHITEHOUSE, 1936

Genus *Pseudagnostus* JAEKEL, 1909

Pseudagnostus chinensis (DAMES)

1883. *Agnostus chinensis* DAMES in RICHTHOFEN'S, *China Bd. 4,* p. 27, pl. 2, figs. 18–19.

1906. *Agnostus fallax* LINNARSSON var. *chinensis* LORENZ, *Zeitschr. deutsch. geol. Gesell. Bd. 58*, s. 112.

1933. *Pseudagnostus orientalis* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 98, pl. 9, figs. 20–22.

1935. *Pseudagnostus orientalis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 110, pl. 3, figs. 7–11, 23.

1935. (?) *Agnostus cyclopyge* SUN, *Pal. Sinica, Ser. B, Vol. 7, Fas. 2*, p. 15, pl. 3, figs. 33 –35, text-fig. 1.

1937. *Pseudagnostus cyclopygeformis* ENDO, *Manchurian Sci. Mus. Bull. 1*, p. 316, pars, pl. 65, figs. 19–22, (?) pl. 68, figs. 8–13, non figs. 14–16.

1937. *Pseudagnostus chinensis* KOBAYASHI, *Jour. Geol. Soc. Japan, Vol. 44*, p. 434, pl. 17, figs. 13a–b.

1939. *Pseudagnostus chinensis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 5, Pt. 5*, p. 157.

Through a restudy on DAMES' type specimens (1937) it was found that his *chinensis* comprises two distinct species. In considering his diagnosis, *chinensis* was restricted to the form which coincides with *Pseudagnostus orientalis*. The other is nothing but *Agnostus hoiformis*. WALCOTT's *chinensis* is a Middle Cambrian agnostid quite different from these Upper Cambrian ones, but agrees with *Peronopsis rakuroensis* (KOBAYASHI).

ENDO's *Pseudagnostus cyclopygeformis* (1937) in figs. 19–22 on pl. 65 and probably in figs. 8–13 on pl. 68 are referable to this species.

Occurrence:—Early Upper Cambrian of Korea, South Manchuria and North China.

Pseudagnostus cyclopygeformis (SUN)

Plate XIX, Figures 6–7.

1924. *Agnostus cyclopygeformis* SUN, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 26, pl. 2, figs. 1a–h.

1933. *Pseudagnostus cyclopygeformis* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 97, pl. 9, figs. 19, 23–24, pl. 10, fig. 7.

1935. *Pseudagnostus cyclopygeformis* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 111, pl. 3, figs. 12–14.

1935. *Pseudagnostus cyclopygeformis* SUN, *Pal. Sinica, Ser. B, Vol. 7, Fasc. 2*, p. 16, pl. 3, figs. 29–32.

1937. *Pseudagnostus cyclopygeformis* ENDO, *Manchurian Sci. Mus. Vol. 1*, p. 316, pl. 68, figs. 14–16, non figs. 8–13, pl. 65, figs. 19–22.

1939. *Pseudagnostus cyclopygeformis* ENDO, *Jubilee Publ. Comm. Prof. Yabe's 60th Birthday, Vol. 1*, p. 6, pl. 1, figs. 13–15.

1939. (?) *Agnostus cyclopyge* SUN, *4 Ann. Pap. Nat. Univ. Peking*, p. 30, pl. 1, fig. 1–3.

As noted on the previous occasion, all of the furrows on the cephalon and pygidium are weakened and the difference in height or convexity is quite reduced between the axis and side-lobe in the South Korean form. A tiny spine is seen on the pygidium in fig. 7. Its outline is more or less narrowing backward in this species but generally expanded in *chinensis*.

SUN's *cyclopyge* from Paoshan, Yunnan (1939), is probably a new species

allied to this species. In his form the glabella appears tripartate, but the division is quite obscure as in the Korean form. The circum-glabellar furrow is, however, strongly impressed. The pygidium has a pair of posterior spines which issue from the points more posterior than those of *cyclopygeformis*. Judging from the associated trilobites the Paoshan horizon is evidently higher than those of *chinensis* and *cyclopyge*.

Occurrence:—*Kaolishania* zone at Sho 16; known also from the *Dictyites* and *Eoorthis* zones in South Korea; widely distributed in Daizanian and Fengshanian in Shantung, Hopei, Laioning and North Korea.

Family Geragnostidae Howell, 1935

Genus *Geragnostus* Howell, 1935

Geragnostus obsoletus Kobayashi, new species

Plate XXI, Figures 16–17.

Description:—Cephalon subquadrate, bordered by a very narrow rim and vaulted toward glabella which is clearly outlined by dorsal furrows and distinctly elevated above cheeks, but apparently undivided, or its trilobation is quite effaced. There is, however, a median tubercle in place of the middle lobe; basal side-lobe obscure.

The pygidium is similar to that of *Geragnostus chiushuensis* (Kobayashi), but evidently longer and has a larger axis relative to the breadth of pleural lobes.

Occurrence:—*Dictyites* zone at Sho 19.

Genus *Geragnostella* Kobayashi, 1939

Geragnostella cambria Kobayashi, new species

Plate XIX, Figure 8.

Description:—Cephalon with conical glabella of moderate length, outlined by weak dorsal furrows, a little longer than a half of the shield, provided with a pair of triangular basal side-lobes, but without any glabellar furrow or tubercle on it; preglabellar axial furrow indiscernible; marginal rim very narrow.

Comparison:—This could be a terminal form of *Pseudagnostus* along the trend of effacement. Nevertheless, the above features are diagnostic of *Geragnostella*. The lack of the median tubercle is the chief distinction of this species from *Geragnostella tullbergi*, the type of the genus.

Occurrence:—*Dictyites* zone at Sho 2 with *Pagodia coreanica*. This is the oldest member of the genus.

Order Redlichiida RICHTER, 1933

Family Redlichiidae POULSEN, 1927

Genus *Redlichia* COSSMANN, 1902

Redlichia saitoi LU

1930. *Redlichia* cfr. *walcotti* SAITO, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 225, pl. 16, figs. 19–21, text-gfi.

1950. *Redlichia saitoi* LU, *Tichih Lunp'ing, Vol. 15*, p. 116, fig.-C₃.

1952. *Latiredlichia saitoi* HUPÉ, *Notes et Mém., No. 103*, p. 151, text-fig. 26-17.

1953. *Redlichia saitoi* CHANG, *Acta Pal. Sinica, Vol. 1*, p. 126, pl. 14, fig. 8.

Compared to *R. chinensis*, the glabella is broader and less conical and the preglabellar area not so broad. What SAITO stated fine pustules on the glabella may be secondary products by alteration of test. His specimen is strongly shortened in the axial direction. In the South Korean specimen the outline is undeformed, although the original convexity is somewaht reduced.

Occurrence:—Dark gray shale of the Beiho slate formation at Dai 1; upper *Redlichia* shale in Chunghwa or Chuwa area, North Korea; archaeocyathid limestone in Hupeh, Central China.

Order Corynexochida KOBAYASHI, 1935

Family Dorypygidae KOBAYASHI, 1935

This group of trilobites was first proposed as a subfamily of the Oryctocephalidae to include *Olenoides* (i. e. *Neolenus*), *Dorypyge*, *Kootenia* and *Holteria*. On that occasion I suggested the belonging of *Notasaphus* to the *Dorypyge* group. Accepting this suggestion, (1939), WHITEHOUSE added *Bonnia*, *Bonniella* and *Notasaphus* to them and promoted the taxon to the family rank. *Notasaphus* has the pygidium indistinguishable from that of *Kootenia*, but the glabella is scarcely expanded forward as seen in typical *Kootenia* and *Olenoides*. The thorax of *N. modocus* is composed of 8 segments, each carrying an axial spine. Kootenidae which RESSER proposed in the same year is evidently a synonym of the Dorypygidae.

In 1953 HUPÉ divided the family into the Dorypyginae comprising *Dorypyge*, *Kootenia* (i. e. *Notasaphus*), *Bonnia*, *Bonniopsis* and (?) *Bonniella* and the Holteriinae HUPÉ including *Holteria*, (?) *Hemirhodon* and *Olenoides*. *Hemirhodon* is, however, better located in the Dolichometopidae (1942). LOCHMAN (1956) referred her genera, *Bonnaria* and *Fordaspis* to the Dorypygidae. The type-species of the former is *Bonnaria salemensis* (RESSER), i. e. *Corynexochus clavatus* WALCOTT, 1916, (pars) which is based on cranidia of meraspid-size showing closer alliance to the Corynexochidae than the Dorypygidae. The latter is a good genus, if restricted to the forms having a preglabellar area as clearly seen in its type-species, *F. nana* (FORD).

The family was well flourished in the Middle Cambrian of Siberia and Central Asia whence new genera were successively described, namely, *Dorypygina*

LERMONTOVA, 1940, *Kooteniella* LERM. 1940, *Prokootenia* LERM. 1940, *Basocephalus* IVSHIN, 1953, *Paraolenoides* IVSHIN, 1953, *Tolanaspis* IVSHIN, 1953, *Bakakovia* SIVOV, 1955, *Kooteniellina* SIVOV, 1955 and *Tabatopygellina* SIVOV, 1955. *Prokootenia* was, however, later synonymized with *Micmacca* with query by LERMONTOVA herself (1951).

Dorypygina has the 6-segmented pygidium, 5 pleurae of which show no sign of marginal border, apparently less convex than those of *Dorypyge;* each pleura produced into a spine which becomes longest at the fourth pleura; pleural and interpleural furrows well impressed. The cranidium is not essentially different from that of *Dorypyge;* nuchal spine well developed. *Dorypygina delicatula* LERM. (Text-fig. 1, j-k) from the late Middle Cambrian of Kuznetsk is the type-species.

TOLL (1899) referred *Proetus (Phateon) slatokowskii* SCHMIDT, 1886, to *Dorypyge* and the reference was later accepted by LERMONTOVA (1926). In 1943 I placed it in *Kootenia* without knowing LERMONTOVA's erection of *Kooteniella* on its basis (1940). At this time she described two new species (*edelsteini* and *cellulifera*). According to IVSHIN (1947) it comprises now 12 species which are widely distributed from Siberia to Central Asia in the early Middle Cambrian with *Erbia*. The most distinctive feature of this genus from *Kootenia* is the strong convexity and the outline of the glabella which is remarkably expanded in the middle part, while in *Kootenia* it is gradually tapering backward.

Tolanaspis IVSHIN, 1953, is allied to *Kootenia* and *Dorypyge*. It resembles *Dorypyge* in strong convexity of the cranidium and distinct eye-ridges, but the glabella is strongly vaulted and scarcely contracted in the anterior part and pits on its two sides are indistinct as in *Kootenia*. The glabella has parallel sides in *T. almaematris* IVSHIN (Text-figs. 1, c–d) which is the type-species. It tapers gradually forward in *T. angustifrons*. The lateral furrows are effaced; test apparently smooth.

Basocephalus IVSHIN, 1953, which includes *B. normalis* IVSHIN, (Text-figs. 1e–f), the type-species, and *B. weberi* IVSHIN, has the cranidium allied to *Olenoides* in outline and convexity, strong lateral furrows, size and position of eyes and prominence of eye-ridges. The glabella is parallel-sided and well rounded in front where the outline of the cephalon is protruded. The associated pygidium is also similar to that of *Olenoides* in the presence of deep pleural furrows and rudimentary interpleural furrows. The axial lobe is composed of 5 rings and the pleural lobe of 4 segments. The long 4th spine is the most obvious distinction from that of *Olenoides*.

Paraolenoides IVSHIN, 1953, is a very aberrant genus of this family having two prominent spines on the glabella which is somewhat narrowing forward; lateral and dorsal furrows quite pronounced. It is represented by three IVSHIN's species, *P. medovi*, *P. vodorezovi* and *P. kassini* (Text-fig. 1, a) where the first is the type-species. All of these three genera occur in the late Middle Cambrian of Kazakstan.

Kooteniellina tubaenia SIVOV, 1955, (Text-fig. 1, g) from the early Middle Cambrian of the East Sayan mountains is monotypic of the genus. Its crani-

dium has an oval smooth glabella, occipital spine, medium sized eyes opposed at the middle of the glabella, oblique eye-ridge, anterior pits on the dorsal furrows and narrow straight frontal rim.

The associated pygidium of the species has the 4-5 segmented rachis and flat pleural lobes provided with pleural and interpleural furrows. These furrows and ribs are, however, truncated by a slightly elevated border which is said to have indentations. It looks more like *Olenoides* than *Kootenia*.

The most distinct biocharacter of the genus is, in my opinion, the oval glabella and strongly arched anterior outline. Insofar as I can figure the outline of the cephalon from this cranidium, it must be unusually triangular.

Tabatopygellina babakoviensis Sivov, 1955, (Text-fig. 1, h), from the late Middle Cambrian of the West Sayan mountains is represented by the cranidium resmbling those of *Bonnia*, *Bonniella*, *Kootenia* and especially *Kooteniellina*. It agrees with the last genus in the subtriangular cephalon, unfurrowed glabella and anterior pits, but the glabella is much slender and nearly as wide as the fixed cheek and the occipital spine apparently absent.

Babakovia Sivov, 1953, ranges from late Lower Cambrian to early Middle Cambrian and occurs widely in the West Sayan, Kuznetsk Alatau, Schorie and Salair mountains. *B. dorypygeformis* Sivov, (Text-fig. 1, i) is the type-species which is intermediate between *Dorypyge* and *Kooteniella*. It may be said that the genus is more allied to the former in the cranidium but so to the latter in the pygidium.

Beside these *Bonniopsis nasuta* Poulsen, 1946, which was procured from the Lower Cambrian of Ellesmereland probably indicates a small early branch of this family. Its anteriorly prolonged acuminate glabella is a unique feature in the Dorypygidae.

In Treatise Poulsen placed *Strettonia* and *Erbiopsis* in the family with question marks. *Strettonia comleyensis* Cobbold, 1931, is founded on imperfect cranidia from the *Protolenus* limestone of Shropshire which resemble the Centropleurinae, Dorypygidae and Protolenidae in one or the other aspect. The associated pygidium is similar to that of *Zacanthoides*. Unless more is known of this trilobite, it is difficult to say its taxonomic position.

Erbiopsis grandis Lermontova, 1940, from the Middle Cambrian of Minusinsk bears, as suggested by its denomination, some resemblances with *Erbia* and its allies, but like in the Dorypygidae the glabella which is ovate, is protruded upon the frontal border. Its pygidium is large, multisegmented and devoid of either marginal border or spines. The thorax is composed of more than 11 segments. In these characteristics this species is quite isolated from the Dorypygidae. On the other hand *Pseudokoldinioidia* Endo belongs most probably to this family. (See page 349).

Distribution:—Cosmopolitan in the Cambrian, but declined in the Upper Cambrian when *Holteria* and *Pseudokoldinioidia* were survided.

Bonnia, *Bonniella*, *Bonniopsis* and *Fordaspis* are all Lower Cambrian samll forms. While *Bonnia* is widely distributed in Eastern Asia, Arctic province and North America, the three others are endemic genera. The clavate glabella

of *Bonniopsis* and the wide posterior flange of the pygidium of *Bonniella* reveal their high specialization. The other genera of the Dorypygidae are moderate in size and mostly Middle Cambrian, but *Kootenia* is long ranged from Lower to Upper (?) Cambrian. *Basocephalus, Dorypygina* and *Paraolenoides* represent wide morphic divergence which took place in Asia in the late Middle Cambrian period.
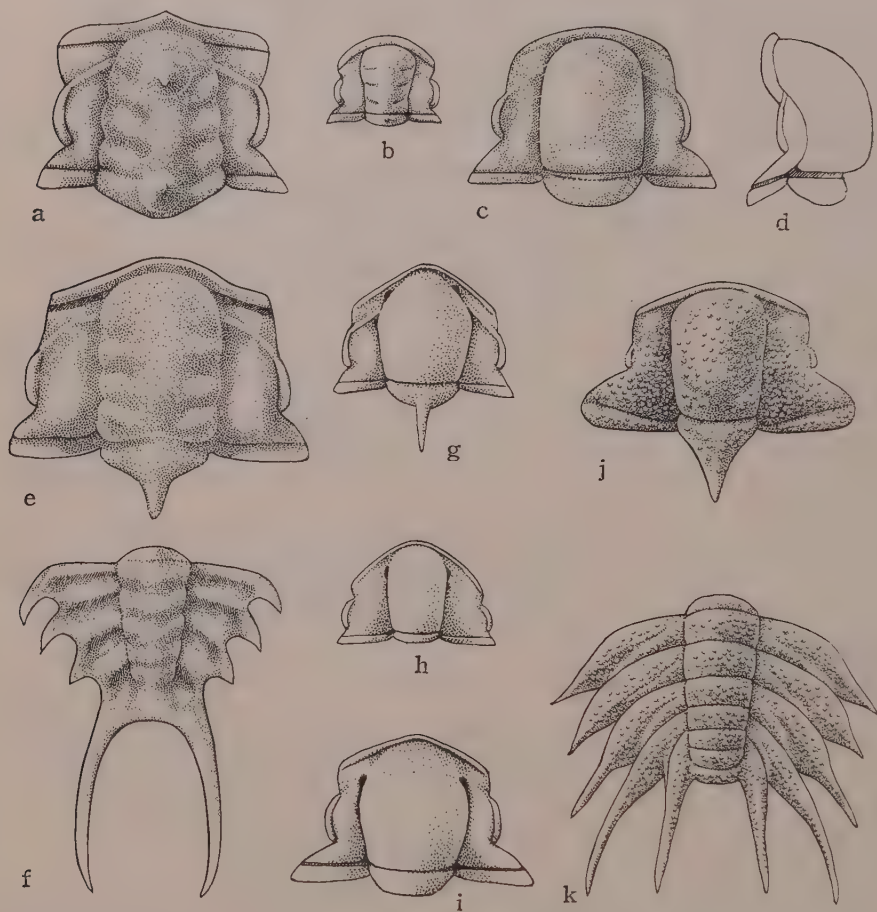
Figure 1. Dorypygidae

a.   *Paraolenoides kassini* Ivshin
b.   *Pseudokoldinioidia granulosa* Endo
c-d. *Tolanaspis almaematris* Ivshin
e-f. *Basocephalus normalis* Ivshin
g.   *Kooteniellina tubaenia* Sivov
h.   *Tabatopygellina bavakoviensis* Sivov
i.   *Babakovia dorypygeformis* Sivov
j-k. *Dorypygina delicatula* Lermontova

Genus *Dorypyge* Dámes, 1883

Dorypyge richthofeni Dames

1883.   *Dorypyge richthofeni* Dames, in Richthofen's *China Bd. 4*, p. 24, pl. 1, figs. 1–6.

1906.   *Dorypyge (Olenoides) richthofeni* Lorenz, *Zeitschr. deutsch. geol. Gesell. Bd. 57*, p. 81, pl. 4, figs. 1–5, *(laiwuensis)*.

1913.   *Dorypyge richthofeni* Walcott, in Willis and Blackwelder's, *Research in China, Vol. 3*, p. 108, pl. 1, figs. 1a, c, d only, *(laiwuensis)*.

1924.   *Dorypyge richthofeni* Sun, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 29, pl. 2, fig. 3b only, *(manchuriensis)*.

1935.   *Dorypyge manchuriensis* Kobayashi, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 160, pl. 22, figs. 9–10, *(manchuriensis)*.

1937.   *Dorypyge richthofeni* Kobayashi, *Jour. Geol. Soc. Japan, Vol. 44*, p. 434, pl. 17, figs. 13a–b.

1937.   *Dorypyge manchuriensis* Resser and Endo, *Manchurian Sci. Mus. Bull. 1*, p. 208, pl. 31, figs. 1–5, pl. 32, figs. 11–12, *(manchuriensis)*.

1937.   *Dorypyge damesi* Resser and Endo, *Ibid. Bull. 1*, p. 209, pl. 31, figs. 14–18.

1937.   *Dorypyge pergranosa* Resser and Endo, *Ibid. Bull. 1*, p. 210, pl. 31, figs. 6–13.

1937.   *Dorypyge matsushitai* Resser and Endo, *Ibid. Bull. 1*, p. 210, pl. 43, figs. 22–24.

1937.   *Dorypyge perconvexa* Resser and Endo, *Ibid. Bull. 1*, p. 211, pl. 44, figs. 11–14, *(perconvexa)*.

1937.   *Dorypyge bigranosa* Resser and Endo, *Ibid. Bull. 1*, p. 212, pl. 44, figs. 15–20.

1937.   *Dorypyge toyamai* Resser and Endo, *Ibid. Bull. 1*, p. 212, pl. 44, fig. 21.

1937.   *Dorypyge leei* Resser and Endo, *Ibid. Bull. 1*, p. 213, pl. 44, figs. 23–25.

1937.   *Dorypyge taitzuensis* Resser and Endo, *Ibid. Bull. 1*, p. 214, pl. 43, fig. 21, *(perconvexa)*.

1938.   *Dorypyge laiwuensis* Kobayashi, *Jour. Geol. Soc. Japan, Vol. 45*, p. 887, fig. 1, *(laiwuensis)*.

1942.   *Dorypyge richthofeni* Resser, *Smithson. Misc. Coll. Vol. 101, No. 15*, p. 16.

1942.   *Dorypyge lorenzi* Resser, *Ibid. Vol. 101, No. 15*, p. 18, *(laiwuensis)*.

1942.   *Dorypyge shantungensis* Resser, *Ibid. Vol. 101, No. 15, p. 19*, *(laiwuensis)*.

1944.   *Dorypyge richthofeni* Endo, *Bull. Central Nat. Mus. Manchoukuo, No. 7*, p. 61.

In 1937 Resser created 12 Manchurian species jointly with Endo. Subsequently in 1942 Resser proposed another 5 new names for North Chinese forms among which *lorenzi* is evidently invalid because the name is given to the same specimens which I denominated *D. laiwuensis* in 1938. Endo on the other hand made a careful comparison among the Manchurian forms with the result he concluded in 1944 that Mapanian *D. damesi* and *D. pergranosa* as well as Taitzuan *D. matsushitai*, *D. bigranosa* and *D. toyamai* all belong to *richthofeni*, because granulation appears to vary "owing to different conditions attending fossilization." He noted further that the variation in granulation bears no value for specific distinction of *Dorypyge*. It is true that the difference of granulation is gradual in *richthofeni*, but I think that the granulation in most specimens I saw is primary, instead of a matter of either preservation or fossilization.

The outline and convexity of the glabella and the strength of its lateral furrows are three other criteria which are probably more important than the granulation of the text. Yet they are not clear-cut distinctions. Here *laiwuensis*,

perconvexa, *manchuriensis* and *laevis* are considered 4 subspecies of *richthofeni*.

The most important characteristic of *laiwuensis* lies in the lateral furrows in three pairs which are all distinct, otherwise it is typical of *richthofeni*. Resser's *shantungensis* i. e. Walcott's *richthofeni* in fig. 1a which bears this characteristic belongs to this subspecies.

Taitzuan *perconvexa* may be a subspecies of *richthofeni* having a bulbous glabella. *Leei* reveals intermediate convexity, although it appears closer to *perconvexa* than *richthofeni* s. str.

Mapanian *manchuriensis* is another subspecies which has a forwardly expanded glabella and relatively broad fixed cheeks. Subspecies *laevis* will be described in the following pages.

Finally, *taitzuensis* is based on a pygidium having 6, instead of 4 or 5 rings on the axis, but it is evident that its difference from *richthofeni* depends on exfoliation by which double segments in the large terminal lobe were exposed.

Occurrence :—Middle Cambrian of North China, South Manchuria and North China, more common in Taitzuan than Mapanian or Tanghsihan. While subspecies *manchuriensis* is Mapanian, subspecies *perconvexa* is Taitzuan.

Dorypyge richthofeni subsp. *laevis* Walcott

Plate XIX, Figures 19-25.

1913. *Dorypyge richthofeni* Walcott, in Willis and Blackwelder's, *Research in China, Vol. 3*, p. 108, pl. 1, figs. 1, 1b, 1e only.
1913. *Dorypyge richthofeni* var. *laevis* Walcott, *Ibid. Vol. 3*, p. 109, pl. 8, figs. 2, 2′, 2a.
1924. *Dorypyge richthofeni* Sun, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 29, pl. 2, figs. 3a, c, d, non 3b.
1937. *Dorypyge kidoi* Resser and Endo, *Manchurian Sci. Mus. Bull. 1*, p. 211, pl. 44, figs. 1–10.
1937. (?) *Dorypyge semicircularis* Resser and Endo, *Ibid. Bull. 1*, p. 214, pl. 43, fig. 21.
1942. *Dorypyge laevis* Resser, *Smithson. Misc. Coll. Vol. 101, No. 25*, p, 17.
1942. *Dorypyge suni* Resser, *Ibid. Vol. 101, No. 25*, p. 19.
1942. *Dorypyge chihliensis* Resser, *Ibid. Vol. 101, No. 25*, p. 19.

The collection at hand contains a laevigate form of *Dorypyge*. Its glabella is distinctly narrowing in the anterior half. The anterior constriction of the glabella is weak but the pits are well impressed on the dorsal furrow. It has no lateral furrows but an occipital one ; occipital ring thickened toward the middle where a median protuberance is present ; fixed cheek narrow and depressed ; eyes of medium size provided with an oblique eye-ridge ; free cheek narrow ; marginal border protruded behind into a short spine. Hypostoma composed of a large swelling central body and a narrow rim from which a triangular flat anterior wing issues on each side.

The associated pygidium has a quinqui-segmented axis and six pairs of spinose pleurae, the fifth pair of which are much elongated and the sixth pair rudimentary. Granulation is undeveloped on the test of either the cephalon or the pygidium, but a small number of granules are found scattered on the

carapace very sparcely.

Comparison:—Var. *laevis* was proposed by WALCOTT for the laevigate form of *richthofeni*. The forwardly narrowing outline of the glabella is another important characteristic which is held also in *richthofeni* in figs. 1 and 1c by WALCOTT (i. e. RESSER's *suni*) and fig. 3a by SUN (i. e. RESSER's *chihliensis*) and *semicircularis* by RESSER and ENDO. The last has granules so coarse that I hesitate to call it *laevis*, but the granulation is not so distinct in the others. A few fine granules are seen in the South Korean form.

Occurrence:—Sho 11 with *Manchuriella convexa;* Changhian in Shantung and Hopei; Taitzuan in Liaoning (?)

Dorypyge (?) grandispinosa RESSER and ENDO

1937. *Dorypyge grandispinosa* RESSER and ENDO, *Manchurian Sci. Mus. Bull. 1*, p. 213, pl. 44, fig. 22.

This species is founded on a pygidium having the extraordinarily stout fifth spine which is quite distinctive from all other species of *Dorypyge*. The pygidium is unusually broad for *Dorypyge*.

Occurrence:—Taitzuan at Tschanghsingtao, Liaoning.

Genus Pseudokoldinioidia ENDO, 1944

1944. *Pseudokoldinioidia* ENDO, *Bull. Centr. Nat. Mus. Manchoukuo, No. 7*, p. 72.

Type-species:—*Pseudokoldinioidia granulosa* ENDO, 1944. (Text-fig. 1, b).

Remarks:—This genus which was erected as a member of the Shumardidae "is characterized by the triangular cranidium, forwardly divergent glabella with rounded frontal margin, and the three paired glabellar furrows, the additional distinctions being the relatively broad fixed cheeks, the very narrow frontal rim and the well defined eyes."

The type cranidium of *P. granulosa* is about 5 mm. long. The dorsal furrow is pronounced on the sides of the glabella, but weakened at its front where the furrow coincides with the frontal marginal furrow. Three pairs of lateral furrows are fairly well marked; occipital furrow moderately deep; occipital ring nearly uniform in breadth and bears a median node. There are fairly large eyes whence low palpebral ridges extend to the glabella a little behind its antero-lateral angles. The two branches of the facial sutures appear to extend diagonally from the ends of the eyes. It is said that "posterolateral limb narrow and extending outward a considerable distance to a rather blunt round end," but this feature is not clearly shown in the original illustration. "Surface of the cranidium finely marked by rather large granules."

In the outlines of the cranidium and glabella, size of the eyes, breadth of the fixed cheeks and other aspects, this trilobite agrees best with the Dorypygidae. As the specimen was collected at Lashushan near Chinchou, Liaotung peninsula, with *Tsinania canens, Pogodia buda, Haniwa sosanensis* and others, it

must be the latest member of the family.

 Distribution:—Fengshanian of Liaoning.

Order uncertain

Dameselloids and leiostegioids are two groups of trilobites having a sub-quadrate or subconical glabella which is generally elongated as far as the frontal border. The pygidium and thoracic segments are spiny in the former while in the latter the segments are commonly truncated at the pleural ends and the pygidium has an entire margin. They were greatly developed in the Asio-Pacific province in the Middle and Upper Cambrian but declined in the Lower Ordovcian. In North America, however, the leiostegioids are fairly well represented in the Upper Cambrian as well as Lower Ordovician. In the Atlantic side, on the contrary, *Drepanura eremita* in Sweden is a solitary damesellid.

Since Henningsmoen had suggested their Conocoryphacean alliance of their glabellar aspect, they were considered ptychoparioids, but so far as I am aware, there is no ptychoaprioid in Asia or the Western Pacific side which is thought ancestral to them. *Inouyina* and *Chakasskia* are early Middle Cambrian genera of North Asia which were provisionally referred to the Damesellidae. Putting aside these two, the family developed sporadically from the late Middle Cambrian to take place of the Dorypygidae and Oryctocephalidae. They agree with one another in the proportional length of the glabella to the cephalon. The damesellids have 12 to 13 segments in thorax, while the number is smaller in the Dorypygidae or Oryctocephalidae, if Lower Cambrian *Lancastria* with 18 thoracic segments and a primitive pygidium is excluded. Therefore it can be said that the caudalization is more advanced in the two families than in the Damesellidae. This, however, may not be a serious objection for the corynexochidian origin of the Damesellidae, in seeing that in the ptychoparioids the greatest number of the thoracic segments is found in the Upper Cambrian *Menomonia*. Because the origin of the dameselloids and leiostegioids is unkown it may be better group them in a secondary order, until its phylogeny can be deciphered.

Family Damesellidae, Kobayashi, 1935

This family was first divided into the Damesellinae, Dorypygellinae and Kaolishaniinae, but the promotion of the last to a separate family is now generally accepted. The Drepanuriinae were erected by Hupé for *Drepanura* and the Missisquoiidae for *Missisquoia* from Upper Cambrian of Vermont to which he added two more genera with query, namely, *Inouyina* and *Chakasskia* from the early Middle Cambrian of Siberia. Not only from morphology but also from the geological distribution the last two are more proper to be accepted as early members of the Damesellinae.

Lately the Chiawangellinae were added to the Damesellidae by Chu. Now,

a new subfamily, Paramenomoniinae, is proposed for *Paramenomonia* Chu. My previous classification of this family is here modified as follows:
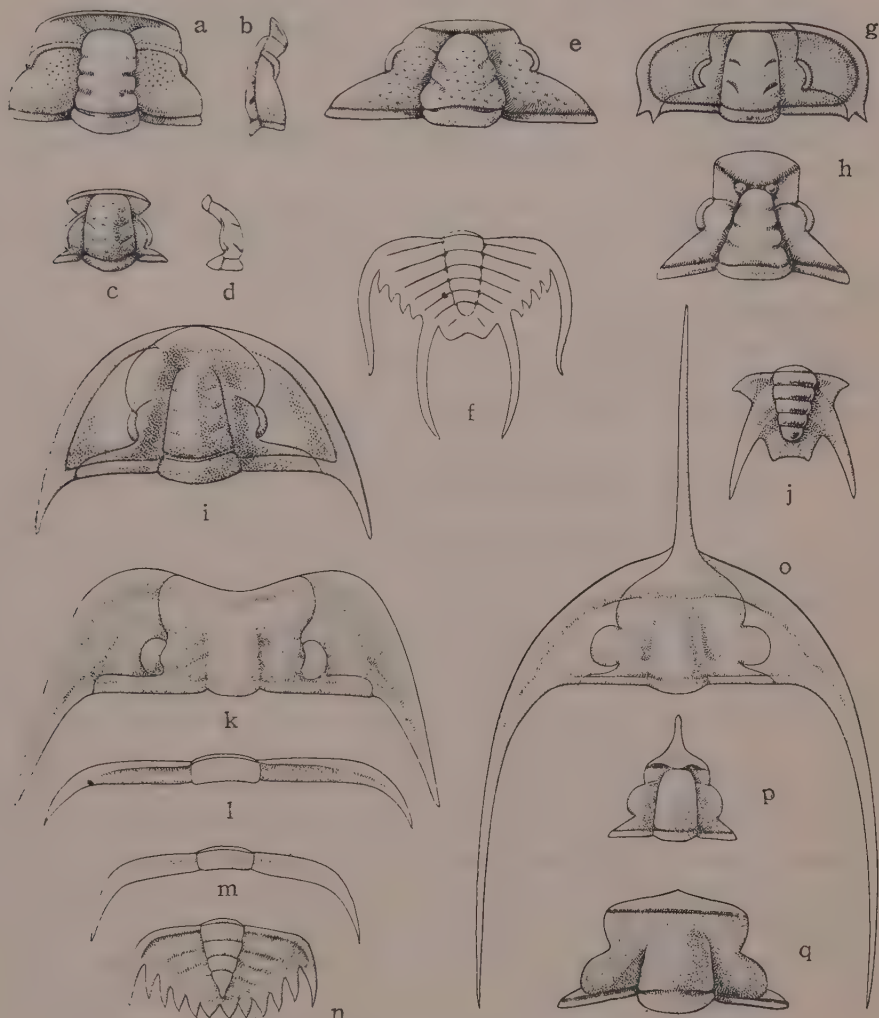
Figure 2. Damesellidae and Kaolishaniidae

a-b. *Prodamesella convexa* Chang
c-d. *Mimana euryrachis* Kobayashi
e. *Damesops convexus* Chu
f. *Damesops bilobus* (Kobayashi)
g. *Taitzehoia wangi* Chu
h. *Paramenomonia conica* Chu
i. *Kabutocrania fossula* Kobayashi
j. *Chiawangella pustulosa* Chu
k-n. *Teinistion lansi* Monke
o. *Shantungia spinifera* Walcott
p. *Shantungia* (*Parashantungia*) *elongata* (Chu)
q. *Shantungia* (*Metashantungia*) *brevica* Chang in Chu

Damesellinae Kobayashi, 1935.

 Stephanocare Monke, 1903, *Damesella* Walcott, 1905.

 Blackwelderia Walcott, 1906, *Blackwelderoides* Hupé, 1955.

 Prodamesella Chang, 1959, *Taitzehoia* Chu, 1959, *Damesops* Chu, 1959.

 (?) *Inouyina* Poletayeva, 1939, (?) *Chaskasskia* Poletayeva, 1939.

Drepanurinae Hupé, 1953.

 Drepanura Bergeron, 1899, *Parablackwelderia* Kobayashi, 1942.

Dorypygellinae Kobayashi, 1953.

 Teinistion Monke, 1903, (text-figs. 2, k–n), *Dorypygella* Walcott, 1905.

 Shantungia Walcott, 1905, (text-fig. 2, o), (*Parashantungia* Chu,ʻ1959,

 · *Metashantungia* Chang, in Chu, 1959).

Chiawangellinae Chu, 1959.

 Chiawangella Chu, 1959.

Distribution:—Middle and Upper Cambrian of Asia, North Europe, ̄and probably Australasia. Most flourished in Kushanian of Eastern Asia.

Subfamily Damesellinae Kobayashi, 1935

Genus *Prodamesella* Chang, 1959

1959. *Prodamesella* Chang, Acta Pal. Sinica, Vol. 7, No. 3, p. 218.

Type-species:—*Prodamesella convexa* Chang, 1959, (text-figs. 2, a–b).

This "differs either from *Damesella* or from *Blackwelderia* in]its broad cranidium, characteristic glabella and glabellar furrows, prominent and transverse eye-ridge, very small palpebral lobes, characteristic frontal border and very stout and short posterior lateral limb". Emphasizing the rectangular glabella and other features, the author referred *Damesella quadrata* Endo, 1937, and *Olenoides manchuriensis* Endo, 1944, to this genus. The cranidium is known only of the type species, but *Olenoides manchuriensis* is represented by the cranidium and pygidium.

Distribution:—Mapanian to Kushanian ; Shantung and Liaoning.

Genus *Taitzehoia* Chu, 1959

1959. *Taitzehoia* Chu, Mem. Inst. Pal. Acad. Sinica, No. 2, p. 104.

Type-species:—*Taitzehoia wangi* Chu, 1959, (Text-fig. 2, g).

Similar to *Stephanocare* and *Damesella*, but fixed cheeks narrower, palpebral lobes somewhat smaller, frontal margin not indented as in *Stephanocare*, ʻfree cheeks much broader in anterior and bearing a short genal and intergenal spine. Pygidium with 6 pairs of long spines the last of which are, [however, shorter than the others. Test smooth.

Distribution:—Kushanian (*Drepanura premesnili* zone) of Liaoning.

Genus *Damesops* Chu, 1959

1959. *Damesops* CHU, *Mem. Inst. Pal. Acad. Sinica. No. 2*, p. 111.

Type-species :—Damesops convexus CHU, 1959, (text-fig. 2, e).

Similar to *Damesella* and *Kaolishania*, but having a more conical glabella, more anterior palpebral lobes and much larger and laterally expanded posterior limbs of fixed cheeks. The associated pygidium of the type species has a pair of triangular projections between the sixth pair of long spines, as seen in "*Blackwelderia*" *biloba* KOBAYASHI, 1942, (text-fig. 2, f) which may be referred to the same genus.

*Distribution :—*Kushanian in Kiangsu and Shantung.

Subfamily Dorypygellinae KOBAYASHI, 1935

Genus *Shantungia* WALCOTT, 1905

Subgenus *Metashantungia* CHANG in CHU, 1959

1957. *Metashantungia* CHANG, *Acta Pal. Sinica, Vol. 5*, p. 31.
1959. *Metashantungia* CHU, *Mem. Inst. Pal. Acad. Sinica, No. 2*, p. 103.

Type-species :—Shantungia (Metashantungia) brevica in CHU, 1959 (i. e. *Shantungia spinifera* WALCOTT, 1905, (pars), in fig. 6e, pl. 14, 1913, (text-fig. 2, q).

This is *Shantungia* having a much broader glabella ; its anterior border narrow and pointed at the middle but the rostral spine is absent.

Distribution :—Kushanian in Shantung.

Subgenus *Parashantungia* CHU, 1959

1959. *Parashantungia* CHU, *Mem. Inst. Pal. Acad. Sinica, No. 2*, p. 102.

Type-species :—Parashantungia elongata CHU, 1959, (text-fig. 2, p).

Differs from *Shantungia* s. str. in the parallel-sided glabella, narrower fixed cheeks and lack of the frontal limb. Palpebral lobes are located not so far back as in *Shantungia*. Accordingly the postero-lateral limb of the fixed cheek is triangular, instead of a broad band in *Shantungia*. The frontal border is thickened toward the middle whenece a short rostral spine issues.

*Distribution :—*Kushanian (*Drepanura premensnili* zone) in Liaoning.

Subfamily Chiawangellinae CHU, 1959

*Diagnosis :—*Damesellidae with relatively large eyes in far posterior position which are connected with glabella by distinct and highly oblique ocular ridges and long pygidium of trapezoidal outline except marginal spines in three pairs the middle ones of which are long and stout.

Genus *Chiawangella* CHU, 1959

1959. *Chiawangella* CHU, *Mem. Inst. Pal. Acad. Sinica, No. 2*, p. 113.

Type-species:—Chiawangella pustulosa CHU, 1959, (text-fig. 2, j).

In the pygidium of the type species the middle spine is expanded on the pleural lobe so wide that its breadth corresponds to the length from the second to the fourth axial ring. *Albertella pacifica* WALCOTT, 1911, is undoubtedly represented by an imperfect pygidium of this genus which has the rounded posterior margin and narrower pleural lobes than those of the types species.

*Distribution:—*Kushanian (*Drepanura premensnili* zone) in Kiangsu and Liaoning.

Subfamily Paramenomoniinae KOBAYASHI, new subfamily

Genus *Paramenomonia* CHU, 1959

1959. *Paramenomonia* CHU, Mem. Inst. Pal. Acad. Sinica, No. 2, p. 115.

Type-species:—Paramenomonia conica CHU, 1959, (text-fig. 2h).

*Diagnosis:—*Opisthoparian trilobites with elongate trapezoidal cranidium and smooth test; glabella with three pairs of furrows, longiconic, extending as far as lenticular anterior border where a circular node exists on each side; palpebral lobe small, located anterior to mid-length of cranidium; posterolateral limb of fixed cheek large, subtriangular; facial sutures slightly divergent anteriorly.

*Remarks:—*As noted by CHU, *Paramenomonia* bears resemblances with *Menomonia* in the relatively anterior eyes and large subtriangular frontal border, but the posterior limb of the fixed cheek is larger and broader and the glabella short and truncato-conical in *Menomonia*. As in this genus, the glabella is subtriangular and provided with three furrows in *Dresbachia* and *Densonella*. None of the Menomoniidae, however, has such a long and large glabella. Furthermore, the facial suture of *Paramenomonia* is opisthoparian, instead of gonatoparian or proparian.

I think quite probable for *Paramenomonia* to be a small highly specialized side branch of the Damesellidae. The eyes are generally opposed at the middle of the glabella in that family, but more anterior in *Parablackwelderia* than in *Paramenomonia*. While the glabella is truncated in most damesellids, it is pointed in *Blackwelderoides*. The frontal border tends to be thickened mesially in *Damesella*, although it is not so thick as in this genus. A pair of anterior nodes is a unique characteristic of this genus.

*Distribution:—*Kushanian in Liaoning, (Taitzuho valley).

Family Kaolishaniidae KOBAYASHI, 1935

This family includes *Kaolishania* SUN, 1924, *Chosenia* KOBAYASHI, 1934, *Mimana* KOBAYASHI, 1935, (text-fig. 2, c-d), *Endonaspis* LOCHMAN, 1956, (i. e. *Wutingia* ENDO, 1935, non MELCHAR, 1926) and probably *Kaolishaniella* SUN, 1935 and *Tasmanocephalus* KOBAYASHI, 1936. *Endocarina* KOBAYASHI, 1956, which was first made a genus of the Kaolishaniinae is, as pointed out recently (1960), more

probably a member of the Calymenidae.

Here the Tingocephalinae HUPÉ, 1955, inluding *Tingocephalus* SUN, 1935, and *Kabutocrania* KOBAYASHI, nov. are provisionally placed in this family.

Distribution:—Upper Cambrian and Lower Ordovician of Eastern Asia and Australasia.

Subfamily Kaolishaniinae KOBAYASHI, 1935

Genus *Kaolishania* SUN, 1924

.1953. *Kaolishania* HUPÉ, *Ann. de Pal. tom. 39*, p. 167.
1956. *Kaolishania* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 27*, p. 13. (See for previous references).
1957. *Kaolishania* LU, *Index Fossils of China, Invert. Vol. 3*, p. 275.
1959. *Kaolishania* LOCHMAN-BALK, in *Treatise on Invert. Pal. O-1*, p. 318.

Type-species:—*Kaolishania pustulosa* SUN, 1924 (i. e. *Kaolishania hopeiensis* RESSER, 1942).

Specific list:—

> *Kaolishania* (?) *granulosa* KOBAYASHI, 1933, (i. e. *Paramansuyella granulosa* ENDO, 1937).
>
> *Kaolishania obsoleta* KOBAYASHI, 1933.
>
> *Kaolishania* (?) *latiura* KOBAYASHI, 1960, (i. e. *Kaolishania orientalis* (GRABAU) by KOBAYASHI, 1935.)

Distribution:—Chaumitian in Eastern Asia, most common in Daizanian.

Kaolishania granulosa KOBAYASHI, 1933

Plate XX, Figures 8-12; Plate XXI, Figure 14.

1913. cfr. *Teinistion* (?) sp. indt WALCOTT, *Cambrian Faunas of China*, p. 22, pl. 9. fig. 4.
1933. *Kaolishania* (?) *granulosa* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 104, pl. 11, figs. 19-20.
1935. *Kaolishania granulosa* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo. Sec. 2. Vol. 4, Pt. 2*, p. 175, pl. 6, figs. 9-11, pl. 9, figs. 14-15.
1937. *Paramansuyella granulosa* ENDO, *Manchurian Sci. Mus. Bull. 1*, p. 359, pl. 70, figs. 1-9.

Not only dorsal carapaces, but also doublures are exposed on the present material. On the cranidium and free cheek the marginal rim is duplicated by the doublures. They are abruptly bent near the genal spine and extended inward as far as the junction between the free and fixed cheeks. On the pygidium the doublure is thickest at the proximal end of the lateral spine. It narrows therefrom to the two sides on the marginal border. At the rear it extends as far as the terminal lobe of the axis. The pygidia in fig. 10. on pl. XX and fig. 14, pl. XXI show a shallow sinuation behind the axial lobe.

Occurrence:—Upper Cambrian or Daizanian in Shantung, Liaoning and South Korea. Illustrated specimens collected from Sho 4 and Sho 16. Because detached carapaces are found together not only at these localities, but also at Dotenri and

other places in the same combination of cranidia, free cheeks, thoracic seg-
ments and pygidia, it can be warranted that they belong to an identical
species.

Kaolishania (?) *latiura* KOBAYASHI, new species

Plate XXI, Figure 19.

1935.   aff. *Kaolishania* (?) *orientalis* KOBAYASHI, non SUN, *Jour. Fac. Sci. Imp. Univ. Tokyo*,
          Sec. 2, Vol. 4, Pt. 2, p. 178, pl. 8, fig. 2.

Pygidium almost twice as long as wide; axial lobe occupying a fifth of
tail-length, terete-conical, composed of 4 rings and a terminal lobe which is
rounded at a fourth of the tail-length from posterior margin; pleural lobe
gently convex; pleural ribs rudimentary, but an anterior one is projected;
postero-laterally into a long spine; antero-lateral facet prominent; marginal
border depressed and somewhat concave; test smooth.

The pygidium from Saishori which I illustrated in my previous paper is
larger. The lateral spine was preserved in its whole length, but the axis is
damaged. The spine is more lateral and much stouter and the marginal border
less depressed in that than the present pygidium.

In the outline this is closer to the pygidium of *Prochuangia mansuyi* than
Mansuyia orientalis. It has a depressed marginal border, but it is absent in
Prochuangia mansuyi which occurs in the basal Upper Cambrian. Like in
Kaolishania granulosa the border is well developed. This pygidium, especially
its pleural lobe, is much broader and the axial lobe more slender, if compared
with *granulosa*. The marginal furrow is absent in this species, but present in
granulosa.

Occurrence:—*Kaolishania* zone as Sho 4 and (?) Saishori.

Genus *Kaolishaniella* SUN, 1935

(?) *Kaolishaniella transita* SUN

Plate XX, Figures 13–16.

1936.   (?) *Kaolishaniella transita* SUN, *Pal. Sinica, Ser. B, Vol. 7, Fas. 2*, p. 62, pl. 3, figs.
          1–7, non, 8–15.

The collection from Sho 16 contains several pygidia which are identifiable
with those of *Kaolishaniella transita*. The pygidium in fig. 15 agrees best with
SUN's in fig. 2 in the straight anterior margin, prominent facet and many other
features. Only a noticeable difference lies in the presence of the interpleural
furrow on the anterior rib which is projected into a spine.

This furrow is, however, obsolete in the pygidium in fig. 14, which resem-
bles SUN's in fig. 4 in the ovat outline. The third pygidium in fig. 13 resem-
bles SUN's in fig. 2, but longer and more or less quadrate in outline. The
concave marginal border is very broad in the fourth in fig. 16. Thus the

variability is fairly great in the Korean as well as the Hopei forms.

The smallest of the Korean form (fig. 14) is still larger than the largest of the Hopei form (Sun's fig. 4). No cranidium of *K. transita* is procured from Sho 16, while the pygidia are there common. This status casts a question on the combination of the detached carapaces. Judging from the association, dimension and general aspect, it is probable that this kind of pygidia belong to *Tingocephalus magnus*.

Occurrence:—Daizanian at Sho 16. Sun's was also obtained from the Daizanian *Kaolishania* zone at Huoluh, Hopei.

Subfamily Tingocephalinae Hupé, 1955

Genus *Tingocephalus* Sun, 1953

1935. *Tingocephalus* Sun, *Pal. Sinica, Ser. B, Vol. 7, Fasc. 3*, p. 61.
1955. *Tingocephalus* Hupé, *Ann. Pal. Tom. 39*, p. 193.
1959. *Tingocephalus* Lochman-Balk, *Treatise on Invert. Pal. O-1*, p. 520.

Type-species:—*Tingocephalus granulosus* Sun.

This genus was established by Sun as a member of the Ceratopygidae probably with the expectation of its possession of a pair of long lateral spines on the pygidium. As noted elsewhere, (1942, p. 298), " *Tingocephalus* has a cranidium similar to that of *Kaolishania* in most features except its larger preglabellar area which is depressed." Hupé erected a subfamily Tingocephalinae in the Dikelocephalidae probably on account of this depressed brim on the cephalon, but he suggested the possible connection with the Leiostegiidae or the Damesellidae. There is, however, no pygidium at the type locality or at the new locality in South Korea which confirms the alliance to the Dikelocephalidae.

If the frontal brim is ignored, the cranidium has many features common with those of *Kaolishania pustulosa*, *Blackwelderia sinensis* and *B. paronai*. The oblique eye-ridge is present in *K. pustulosa*, but its fixed cheek is narrower than that of *Tingocephalus granulosus*. *B. sinensis* has the posterior lobe extending into the cheek from the glabella to form a ridge in a way. *B. paronai* is especially similar to *Tingocephalus granulosus* in the relatively large preglabellar depression which is clearly defined from the rolled fixed cheek. It is quite probable that the large frontal brim of *T. granulosus* is genetically related to such a depression.

Distribution:—Daizanian of Eastern Asia.

Tingocephalus concavolimbatus (Endo)

1937. *Parakoldinioidia concavolimbata* Endo, *Manchurian Sci. Mus. Bull. 1*, p. 330, pl. 70, figs. 20–22.

This species is closely allied to *T. granulosus*, but they may be specifically distinct, because the glabella looks more slender and the fixed cheek much broader in the former than in the latter. The frontal brim appears triangular

and concave. The ∧-shaped posterior ridge is seen in fig. 20 to extend from the glabella into the cheek.

Occurrence :—Daizanian at Tschanghsingtau, Liaoning.

Tingocephalus magnus KOBAYASHI, new species

Plate XX, Figure 17.

Description :—Cranidium exclusive of postero-lateral limb subquadrate ; glabella truncato-conical, more abruptly expanded in posterior, fairly convex ; axial part strongly elevated ; three pairs of glabellar furrows indicated by rounded pits near lateral margin in anterior, a little elongated depression in middle and well developed oblique furrows in posterior ; posterior lobe connected with reniform basal side-lobe on fixed cheek where dorsal furrow is interrupted by this elevation ; occipital furrow profound, broadly arcuate and bent antero-laterally near extremities ; occipital lobe narrow, but somewhat thickened near axis ; fixed cheek nearly as broad as glabella, elevated toward palpebral lobe which is located far back ; palpebral ridge prominent and oblique ; frontal brim large, flat or depressed ; its boundaries with swelling fixed cheeks divergent widely from antero-lateral angles of glabella. Test smooth.

Measurment and comparison :—The holotype cranidium is 24 mm. long and its glabella 16 mm. long and 9 mm. and 13 mm. broad respectively at the frontal and occipital lobe. It is unusually large because the known cranidia of *T. granulosus* and *T. concavolimbatus* are all 10 mm. or less in length. This cranidium can be distinguished from that of *granulosus* by its shorter and more conical glabella, strongly pitted glabellar furrows, highly oblique eye-ridge, strongly elevated palpebral lobe at posterior position and large frontal brim. In *T. granulosus* the brim is half as long as the glabella and the test granulose.

Occurrence :—Daizanian ; Sho 16.

Genus *Kabutocrania* KOBAYASHI, new genus

Type-species :—*Kabutocrania fossula* KOBAYASHI, new gen. and sp.

This genus is well characterized by the broad cephalon of low convexity, relatively long conical glabella truncated in front, medium sized eyes opposed at its mid-length, oblique eye-ridges, remarkably distinct preglabellar depression and forwardly divergent facial sutures.

In the last feature it resembles *Lioparia*, but they are different in many other aspects. It is more probable that such a form was derived from *Blackwelderia*-like form by inward migration of the anterior sutures. In *Tingocephalus* the facial suture is not so advanced, but the greater development is recongnized in the frontal brim. Its glabella is shortened, causing the lateral expansion of the posterior part, but the glabella is normal in this genus.

Distribution :—Changshanian of Eastern Asia.

Kabutocrania fossula Kobayashi, new gen. and sp.

Plate XX, Figure 19, text-figure 2, i.

Description:—Cranidium with a long conical glabella, three pairs of lateral pits, thick persistent occipital furrow which is arcuate with backward convexity, fixed cheeks of moderate breadth, posterior eyes and relatively small subtriangular frontal brim; brim only a third as long as glabella; facial sutures nearly parallel to each other in front of eyes, but almost diagonal on marginal border; eye-ridge oblique and weak; palpebral lobe medium in size; fixed cheek extending laterally behind the lobe. Test smooth. The associated free cheek bears a genal spine.

The type cranidium is 16 mm. long and the glabella 12 mm. long and 8 mm. broad at the occipital ring.

Occurrence:—Changshanian at Sho 1, in association with *Billingsella pumpellyi*, *Hypseloconus coreanicus* and *Chuangia nitida*.

Family Leiostegiidae Bradley, 1925

The Illenurinae and Iranaspinae are here excluded, but the Lloydiinae tentatively included in this family, beside the Eochuangiinae and Leiostegiinae which are typical of the family.

Distribution:—Middle Cambrian to Lower Ordovician; Asia, and North America.

Subfamily Eochuangiinae Kobayashi, 1935

Diagnosis:—Leiostegiidae with rectangular or subquadrate glabella. Pygidium subtriangular with posterior axial spine.

Remarks:—Beside *Eochuangia* (text-fig. 3d–f) this subfamily includes probably *Ataktaspis* Lochman and Duncan, 1944, from the Dresbachian of North America.

In spite of the lack of the pygidium, I have provisionally placed *Girandia* (text-fig. 3j) in this subfamily, because of the chuangioid cranidium and granulate test. The strengh of its lateral furrows and also the granulation of its cranidium remind one also of the Damesellinae. However, it is excluded from the Damesellinae, because the cranidium is not so broad as those of the Damesellinae. The intramarginal facial sutures on the frontal border is a further distinction.

Distribution:—Late Middle Cambrian to early Upper Cambrian; Eastern and (?) Northern Asia and North America.

Subfamily Leiostegiinae Bradley, 1925

This subfamily is represented in Eastern Asia by *Prochuangia* and *Chuangia* in the early Upper Cambrian, *Chuangiella* in the late Upper Cambrian and

Leiostegioides in the Lower Ordovician. *Chuangiella elongata* (text-fig. 3c) is intermediate in character and also in age between *Chuangia* and *Leiostegium*. *Chuangiella intermedia* Kobayashi, 1935, from Alaska bears affinities not only with *Leiostegium*, but also with *Cholopilus*. Its age is, however, evidently older than these allies, because it is found together with *Briscoia*. Much remains to be studied on *Leiostegioides*, but it differs from *Leiostegium* by the more anterior position and probably smaller size of the eyes.

    Iranochuangia proposed on this occasion indicates a branch of this subfamily in Southwestern Asia which is easily distinguished from *Chuangia* and other allied genera by the lateral protrusion of the anterior part of the glabella.
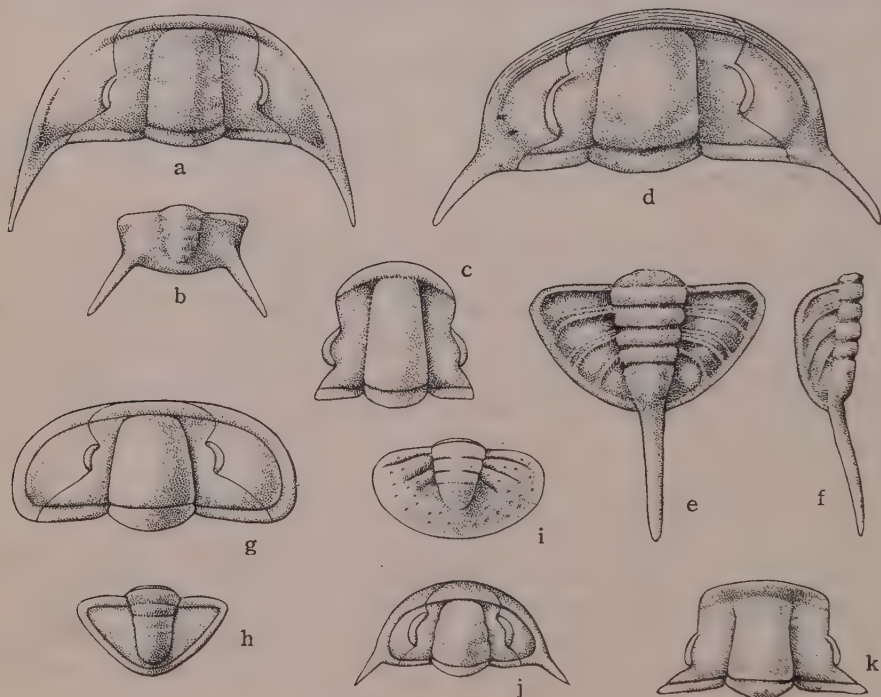
Figure 3. Leiostegiidae

a-b. *Prochuangia mansuyi* Kobayashi
c. *Chuangiella elongata* Kobayashi
d-f. *Eochuangia hana* Kobayashi
g-h. *Prolloydia orientalis* Kobayashi
i. *Chuangioides punctatus* Chu
j. *Girandia typa* Kobayashi
k. *Iranochuangia persicum* (King)

    Chuangioides Chu, 1959, was founded on the pygidium called *Chuangioides punctatus* Chu, 1959, (text-fig. 3i) which resembles the pygidium of *Chuangia* in most aspects, but the outline is subelliptical, instead of semielliptical or semicircular in *Chuangia*, because the anterior margin is more strongly arcuate and the antero-lateral margin fairly rounded in *Chuangioides*. The type-species occurs in the lower Kushanian formation of Shansi in association with *Blackweldaria paronai*. The genus is considered ancestral to *Chuangia* by Chu.

Unfortunately the cephalon is unknown of this genus.

Distribution:—Late Middle Cambrian (?), Upper Cambrian and Lower Ordovician ; Southern and Eastern Asia, North America and South America.

Genus *Prochuangia* KOBAYASHI, 1935

1935. *Prochuangia* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 185.
1953. *Prochuangia* HUPÉ, *Ann. de Pal. 39*, p. 177.
1957. *Prochuangia* LU, *Index Fossils of China, Invert. Vol. 3*, p. 275.
1959. *Prochuangia* LOCHMAN-BALK, in *Treatise on Invert. Pal. O-1*, p. 319.

Type-species:—*Prochuangia mansuyi* KOBAYASHI, 1935, (text-figs. 3a–b).

Remarks:—Beside the type-species, this genus includes the followings :

Conocephalites quadriceps DAMES, 1883.

Prochuangia posterospina KOBAYASHI, 1935.

Prochuangia angusta KOBAYASHI, 1935.

Prochuangia imamurai ENDO, 1944.

This genus agrees with Lower Ordovician *Evansaspis* in the presence of a pair of postero-lateral spines on the pygidium. In the former, however, these spines are prolongations of pleural ribs and there is no marginal border on the pygidium, while the latter has a marginal border strongly depressed or distinctly defined by a deep furrow and the spines issue from the border.

For the comparison of the genus with *Mansuyia* the reader is referred to my paper, 1952.

Distribution:—Early Upper Cambrian of Eastern and Southeastern Asia.

Genus *Chuangia* WALCOTT, 1911

(i. e. *Schantungia* LORENZ, 1906, non *Shantungia* WALCOTT, 1905)

1906. *Schantungia* LORENZ, *Zeitschr. deutsch. Geol. Gesell. Bd. 58*, s. 93.
1911. *Chuangia* WALCOTT, *Smiths. Misc. Coll. Vol. 57, No. 4*, p. 83.
1913. *Chuangia* WALCOTT, *Research in China, Vol. 3*, p. 170.
1924. *Chuangia* SUN, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 57.
1935. *Chuangia* SUN, *Ibid. Ser. B, Vol. 7, Fasc. 2*, p. 19.
1955. *Chuangia* HUPÉ, *Ann. de Pal. Tom. 41*, p. 181.
1957. *Chuangia* LU, *Index Fossils of China, Invert. Vol. 3*, p. 275.
1959. *Chuangia* LOCHMAN-BALK, *Treatise on Invert. Pal. O-1*, p. 310.

Type-species:—*Ptychoparia* (?) *batia* WALCOTT, 1905.

Remarks:—The outline of the glabella is quadrate and elongated as far as the frontal furrow, but never protruded into the frontal border as in *Leiostegium*. Generally it tapers forward to some degrees. Its lateral sides may show shallow concavity, but none of them has such a lateral protrusion as seen in Iranian forms. In considering their isolated occurrences the morphic difference is evaluated more than specific value.

Some 25 species are so far described from Eastern Asia under this generic name. They are *frequens* (DAMES, 1883), *buchruckeri*, *monkei*, *crassa* (LORENZ,

1906), *fragmenta, nais, nitida,* (WALCOTT, 1911), *meridionalis* (MANSUY, 1916), *ka-wadai, transversalis* (1933), *taihakuensis* (1935), *convexa, curvata, tawenkouensis, subquadrangulata, yuani,* (SUN, 1935), *lata, puteata, tolli, transversa, kuantungensis, convoluta,* (RESSER and ENDO, 1937), *endoi, hopeiensis, huoluensis* (RESSER, 1942), *planicaudata* and *conica* (ENDO, 1944).

Conocephalites frequens (text-figs. 4d–e) is well characterized by the slender glabella, posterior eyes and the wide limb of the fixed cheeks. This species agrees with *Chuangia nais* (text-fig. 4a) in the narrow glabella, but in *nais* it is less conical and eyes are much smaller and opposed at the middle of the glabella. *Chuangia curvata* is probably a member of the same specific group, but has a small median node on the neck ring.

As pointed out by WALCOTT (1913), *Schantungia buchruckeri* (text-fig. 4c) is synonymous with *Chuangia nitida.* Therefore the latter is invalid. The straight or even concave and erected frontal rim, distinct diagonal eye-ridges and large eye-bands are characteristic of this species. *Ch. transversalis* (or *Ch.*
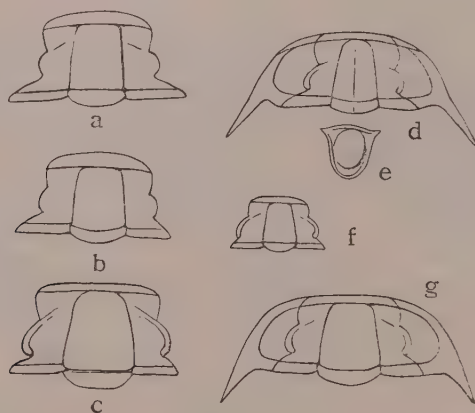
Figure 4. *Chuangia*

a. *Chuangia nais* WALCOTT   b. *Chuangia batia* (WALCOTT)
c. *Chuangia buchruckeri* (LORENZ)   d–e. *Chuangia frequens* (DAMES)
f. *Chuangia monkei* (LORENZ)   g. *Chuangia kawadai* KOBAYASHI

transversa) is allied to it, but the glabella is broader and less convex and eye-ridges are more prominent in *buchruckeri. Ch. huoluensis* (i. e. *nitida* by SUN, 1935), *Ch. subquadrangulata* SUN, 1935, *Ch. endoi* (i. e. *nitida* by ENDO, 1937), *Ch. planicaudata* and *Ch. conica* belong to the same specific group, if they are not conspecific with *buchruckeri.*

Ch. batia (text-fig. 4b) combined with *Ch. kawadai* (text-fig. 4g) and *Ch. taihakuensis* consitute a large group of this genus having a fairly broad glabella and medium sized eyes, but the eye-ridges are usually weak or obsolete. In *Ch. kawadai* the glabella is subrounded in anterior, but quadrangular in the two others. In *Ch. batia* the frontal depression is well developed and the up-turned rim convex forward, while the rim is nearly transversal and sharply edged on the top on *kawadai* and *taihakuensis.*

Most of the remaining species belong to this group. *Ch. puteata* was identi-

fied with *Ch. batia* by ENDO, 1944.   *Ch. convexa*, *Ch. lata*, *Ch. tolli*, *Ch. kuantungensis* and *Ch. convoluta* are members of the *batia* group, but all have the glabellae of greater convexity and the last in particular has the strongly convex cranidium.   *Ch. yuani* and *Ch. tawenkouensis* are two species resembling *Ch. kawadai*, but the glabellar outline is quadrangular in the latter and contracted in the former.   The relative breadth of the glabella to the fixed cheek is also different among them.

Schantungia monkei (text-fig. 4f) is a small species distinct from all others in the narrow subcylindrical glabella and well developed eye-bands.   *Schantungia crassa* is nom. nud. *Chuangia fragmenta* may be a *Maladioides* (1933) and *Ch. meridionalis* MANSUY, 1916, is possibly an *Anomocarella* (1944).   *Ch. nais* by MANSUY, 1915, which has a pair of spines on the pygidium must be a *Prochuangia* or a *Kaolishania*, while another of the same author, 1915, from the *Prosaukia* zone may be a *Kaolishania*.   Eliminating them, only *Chuangia nais* by MANSUY, 1916, from the *Billingsella tonkinensis* zone remains as a representative of the genus in Tonkin-Yunnan border.   *Schantungia* cfr. *frequens* by REED, 1910, from Spiti was considered by the author to be congeneric with *Ch. nitida*, but the congenity is quite improbable, because it is found in Spiti together with *Metadiscus haimantensis*, *Oryctocephalus* and ptychoparids in the same horizon. *Ch. wadapurensis* REED, 1934, and *Chuangia* (?) *subangulata* REED, 1934, from Kashmir, both having frontal limbs of moderate size, must be excluded from *Chuangia*.   Finally, *Chuangia batia* by SUN, 1924, was later referred by the author to *Mansuyia orientalis* (1935).

Distribution :—Eastern and Southeastern Asia ; early Upper Cambrian.

Genus *Iranochuangia* KOBAYASHI, new genus

Type-species :—*Chuangia nais* var. *persicum* KING, 1937, (text-fig. 3k).

Diagnosis :—Similar to *Chuangia*, but having the glabella abruptly swollen laterally at the anterior end and the frontal rim remarkably depressed and flattened.

Remarks :—Because these aspects are seen also in *Chuangia nais* by KING, 1930, from Narghun, it belongs to the same genus, but its glabella is evidently much broader than in the type-species.   Its glabellar furrows are apparently weakened at the lateral projections.   Therefore this form must be distinguished from *Iranochuangia persicum*.   *Iranochuangia narghunensis* is proposed for KING's form in 1930.

Distribution :—Early Upper Cambrian of Iran.

Genus *Mansuyia* SUN, 1924

1924.   *Mansuyia* SUN (pars), *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 50.
1952.   *Mansuyia* KOBAYASHI, *Trans. Proc. Pal. Soc. Japan, N.S. No. 5*, p. 146. (See for previous references).
1953.   *Mansuyia* HUPÉ, *Ann. de Pal. Vol. 39*, p. 179.
1957.   *Mansuyia* LU, *Index. Fossils of China, Invert. Vol. 3*, p. 282.
1959.   *Mansuyia* LOCHMAN-BALK, in *Treatise on Invert. Pal. 0-1*, p. 319.

Type-species :—Mansuyia orietalis Sun, 1924, (pars).

Remarks :—A lengthy discussion on this genus was given in 1952. *Chuangia batia* by Sun, 1924, *Paramansuyia planilimbata* Endo, 1937, *Paramansuyia taianensis* Resser, 1942, and *Mansuyia endoi* Resser, 1942, belong to *Mansuyia orientalis*. Other species of the genus are as follows:

    Mansuyia tani Sun, 1935

    Paramansuyia chinensis Endo, 1939

    Paramansuyia puteata Endo, 1937

    Mansuyia manchurica Kobayashi, 1952

Mansuyia maladiformis Kobayashi, 1935, may be more allied to *Pseudokainella* than *Mansuyia* (1960). Here two new species, *M. hopeiensis* and *M. trigonalis*, are described.

Distribution :—Medeaval and late Upper Cambrian of Eastern Asia.
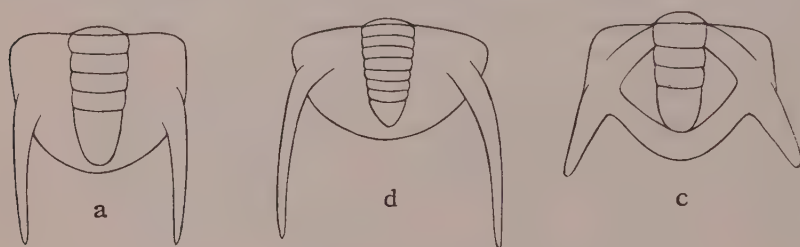
Figure 5. *Mansnyia*

    a. *Mansuyia hopeiensis* Kobayashi, n. sp.

    b. *Mansuyia tani* Sun

    c. *Mansuyia trigonalis* Kobayahi, n. sp.

Mansuyia hopeiensis Kobayashi, new species

Text-figure 5a.

1934. *Mansuyia orientalis* Sun, *Pal. Sinica, Ser. B, Vol. 4, Fasc. 4*, p. 50, pl. 3, figs. 7i–j only.

Distinguished from *M. orientalis*, *M. tani*, (text-fig. 5, b), and other species of this genus by the elongated outline of the pygidium, relatively broad axial lobe, obscure segmentation, absence of distinct marginal border and particularly by the subparallel margins and spines.

Occurrence :—Late Upper Cambrian Fengshan limestone ; Yehli, Machiakou in Hopeh.

Mansuyia trigonalis Kobayashi, new species

Plate XX, Figure 11 ; Plate XXI, Figure 18, Text-figure 5c.

Description :—Pygidium subtriangular and slightly inflated ; anterior margin straight and forms an obtuse angle with lateral margin which is nearly in line with lateral spine ; posterior outline rectangular, but rounded at apex ; axial

lobe a thrid as wide as anterior margin, composed of 3 or 4 rings and a terminal lobe which is abruptly rounded at the end ; an anterior pleural rib protruded postero-laterally ; marginal border fairly thick and well defined between the spines ; text smooth.

Occurrence:—*Dictyites* zone ; Sho 6.

Subfamily Lloydiinae Kobayashi, 1935

Genus *Prolloydia* Kobayashi, new genus

Diagnosis:—Cephalon broad ; glabella long, subovate and strongly convex ; no furrows on glabella except for an occipital one ; eyes of medium size, set close to glabella at a little anterior to its mid-length ; postero-lateral limb of fixed cheek large, subtrigonal ; free cheek broad ; facial sutures divergent in anterior and posterior to eyes and intramarginal for a short distance on frontal rim.   Pygidium triangular ; axis divided into three anterior rings and a long posterior lobe ; only first rib and furrow marked off on pleural lobe ; marginal border narrow and depressed.   Test smooth.

Type-species:—*Prolloydia orientalis* Kobayashi, new species.

Remarks:—The free cheek appears to have no genal spine, but it requires a further confirmation for its absence.   This genus has some features common with *Kaolishania*, *Lloydia* and *Chuangiella*.   In the general configuration of the cranidium it is similar to *Kaolishania*, but the glabellar furrows are all effaced and granules absent on the test.   Compared to this genus, the frontal rim is more rounded and less raised and the glabella more conical in *Lloydia*.   Its type-species is *Bathyurus bituberculata*.   As suggested by the name, that species has a pair of posterior side-lobes which are completely isolated from the main part of the glabella by posterior lateral furrows.   The pygidium of *Bathyurus saffordi* Billings which is considered a *Lloydia*, has the well rounded pygidium with a multisegmented axial lobe.   In *Chuangia* and *Chuangiella* the glabella is less conical or less convex, the fixed cheek broader and the eyes are located more posteriorly.   Accordingly the postero-lateral limb of the fixed cheek is smaller in them than in *Prolloydia*.   The pygidium of *Chuangia* is generally broad, the axis relatively narrow and the marginal border ill-defined.

With the find of *Prolloydia* it is suggested that the Lloydiidae are located between the Kaolishaniinae and the Leiostegiinae, although the subfamily is closer to the Leiostegiinae.

Prolloydia orientalis Kobayashi, new species

Plate XX, Figure 21–25 ; Text-figures 3g–h.

Because this is monotypic of *Prolloydia*, its diagnosis is applied to the description of the species.   The holotype cranidium is 14.5mm. long and about 24mm. broad ; its glabella 13.3 mm. long and 9.2 mm. broad.

The axial lobe of the pygidium is very narrow, prominant and bordered by

axial furrows which are deep and wide. These furrows join each other behind
the axial lobe where they become shallow. Separated by a narrow space, the
lobe appears to terminate at some distance inside of the marginal rim.

Occurrence:—*Dictyites* zone ; Sho 1.

Family Pagodiidae Kobayashi, 1935

This family consists of the Pagodiinae and the Ordosiinae Lu, 1954.

Distribution:—Middle Cambrian to Lower Ordovician ; Asia, North America
and Australia where in the last the family is represented by *Idamea* White-
house, 1939, and probably *Pagodia* (Öpik et al 1957).

Subfamily Pagodiinae Kobayashi, 1935

Genus *Pagodia* Walcott, 1905

1905.   *Pagodia* Walcott, *Proc. U. S. Nat. Mus. Vol. 29*, p. 63.
1955.   *Pagodia* Hupé, *Ann. de Pal. Tom. 41*, p. 181.
1957.   *Pagodia* Kobayashi, *Jour. Fac. Sci. Univ. Tokyo, Sec. 2, Vol. 10, Pt. 3*, p. 371. (See
        for previous references).
1957.   *Pagodia* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 273.
1959.   *Pagodia* Lochman-Balk, in *Treatise on Invert. Pal. 0–1*, p. 310.

This is a group of trilobites, similar to *Chuangia*, but much smaller, its
test seldom smooth and palpebral ridges are usually absent. The glabella is
subcylindrical, somewhat tapering forward and provided with three pairs of
lateral furrows in different strength. The frontal rim is wire-like and rounded
on the top. In *Chuangia*, on the other hand, the doublure is often up-raised
to form a crest at the frontal rim. Such a crest is frequently seen to run
diagonally across the lateral border in *Chuangia*. The free cheek of *Pagodia*
has been unknown, but there is one referable to *Pagodia coreanica* which is
quite distinct from the free cheek of *Chuangia* on this account. In the pygi-
dium the furrows are not so much obsolete in *Pagodia* as in *Chuangia*. The
marginal border is generally present in the former, but absent or undeveloped
in the latter.

Eliminating dubious forms (1957), 13 species are retained in *Pagodia* as
follows :—

> *Pagodia bia* Walcott, 1905
> *Pagodia buda* Resser and Endo in Kobayashi, 1933
> *Pagodia chaoi* Kobayashi, 1931
> *Pagodia damesi* Kobayashi, 1931
> *Menocephalus* (?) *depressus* Walcott, 1905
> *Pagodia dolon* Walcott, 1905
> *Pagodia lorenzi* Kobayashi, 1931
> *Pagodia lotos* Walcott, 1905
> *Pagodia macedo* Walcott, 1905
> *Pagodia paraquadrata* Endo, 1937

Pagodia richthofeni KOBAYASHI, 1931
Pagodia shumardoides KOBAYASHI, 1935
Pagodia thaiensis KOBAYASHI, 1957

The fourteenth species is *Pagodia coreanica* of which the cranidium, free cheek and pygidium are known.
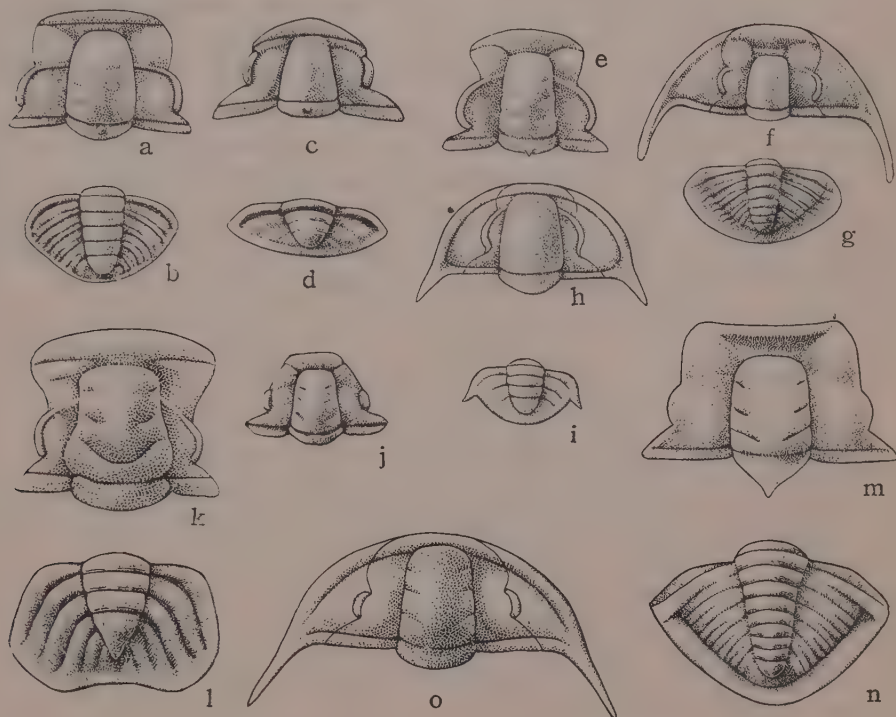
Figure 6. Pagodiidae

a-b. *Taitzuia quadrata* CHANG
c-d. *Chuangiopsis sibirica* (SIVON)
e. *Peichiashania rectangularis* (ENDO)
f-g. *Poshania poshanensis* CHANG
h. *Lisania bura* (WALCOTT), (cranidium), and *Lisania agonius* (WALCOTT), (free cheek)
i. *Aojia spinosa* RESSER and ENDO
j. " *Taitzuia* " *triangulata* ENDO
k-l. *Lichengia onigawara* KOBAYASHI
m-n. *Ordosia fimbricauda* LU
o. *Pagodia coreanica* KOBAYASHI

Distribution:—Upper Cambrian, but rare in its lower part; Liaoning, Hopei, Shantung, South Korea, Peninsular Thailand and probably Australia and (?) Siberia.

Pagodia coreanica KOBAYASHI, new species

Plate XIX, Figures 27–29, Text-figures 6o.

Description:—Glabella cylindro-conical, outlined by deep dorsal furrow,

strongly convex and provided with three pairs of lateral furrows; anterior furrow rudimentary; middle and posterior ones fairly distinct; occipital furrow deep; occipital ring thickened toward axis; fixed cheek narrow, tolerably convex; eyes of moderate size, located at about the mid-length of glabella; frontal groove deep; frontal rim wire-like and well arcuate; facial suture somewhat divergent forward from eyes; small pustules sparsely distributed.

A left cheek at hand has a short genal spine; marginal furrow shallows backward, while the posterior one tends to run into the spine. A pygidium from the same locality has a prominent subcylindrical axial lobe, high above the moderately convex pleural lobes with three strongly convex ribs of sub-equal strength beside the anterior ridge; marginal border narrow.

Comparison:—In the arcuate frontal margin of the cranidium this species resembles *Pagodia lotos* Walcott and *P. macedo* Walcott, but the glabella is much narrower in *macedo* and the lateral furrows are all effaced in *lotos*.

Occurrence:—*Dictyites* zone; Sho 2.

Genus *Lisania* Walcott, 1911

1911. *Lisania* Walcott, *Smithson. Misc. Coll. Vol. 57, No. 4*, p. 82.
1913. *Lisania* Walcott, *Cambrian Faunas of China*, p. 163.
1935. *Lisania* Kobayashi, *Jour. Fac. Sci. Imp. Univ. Tokyo. Sec. 2, Vol. 4, Pt. 2*, p. 161.
1937. *Aojia* Resser and Endo, *Manchurian Sci. Mus. Bull. 1*, p. 172.
1953. *Aojia* Hupé, *Ann. de Pal. Vol. 39*, p. 135.
1953. *Lisania* Hupé, *Ibid.* p. 181.
1957. *Lisania* Lu, *Index Fossils of China, Vol. 3*, p. 271.
1957. *Aojia* Lu, *Ibid. Vol. 3*, p. 271.
1959. *Aojia* Lochman-Balk, in *Treatise on Invert. Pal. 0-1*, p. 311.
1959. *Lisania* Lochman-Balk, *Ibid. 0-1*, p. 312.

Type-species:—*Anomocarella* (?) *bura* Walcott, 1905, (Text-fig. 6h, cranidium).

Remarks:—The distinctive features of this genus are the large oblong glabella, obsolete lateral furrows, narrow fixed cheeks, large semicircular palpebral lobes, nearly flat frontal rim and the lack of the frontal limb. The palpebral ridge is often present and the occipital spine sometimes present. The genal spines are usually present. Associated pygidia generally have entire margins, but a pair of short spines are met with in some forms.

As noted elsewhere (1935), "*Aojia* is extremely close to *Lisania*", although no word was spared by the authors of *Aojia* for their comparison. *Aojia spinosa* Resser and Endo, 1937, is the type-species of their genus. Its holotype cranidium from Tangshihling (Resser and Endo, 1937, pl. 45, fig. 20) has a nuchal spine like *L. alata*, but the spine is absent in its paratype cranidia (Pl. 60, figs. 1-4). *A. spinosa* has sometimes a pair of short spines on its pygidium, but the spines are absent in most other species of *Aojia*. The pygidia of *Lisania* are either lenticular or semi-circular in outline and both kinds are found also in *Aojia*. Thus I failed to see any distinction between the two genera.

There are more than 25 species which were placed either in *Lisania* or

Aojia. They are as follows:

      Arionellus agonius WALCOTT, 1905, (Text-fig. 6h, free cheek)

      Arionellus ajax WALCOTT, 1905

      Arionellus alala WALCOTT, 1905

      ? *Menocephalus belenus* WALCOTT, 1905

      Ptychoparia tellus WALCOTT, 1905

      Anomocare biston WALCOTT, 1905

      Ptychoparia undata WALCOTT, 1906

      Lisania ? hsuchiachuangensis SUN, 1924

      Lisania rectangularis SUN, 1924

      Aojia spinosa RESSER, 1937, (Text-fig. 6i)

      Aojia longispina RESSER and ENDO, 1937

      Aojia pechiliensis RESSER and ENDO, 1937

      Aojia fracta RESSER and ENDO, 1937

      Aojia tumida RESSER and ENDO, 1937

      Aojia yentaiensis RESSER and ENDO, 1937

      Aojia luna RESSER and ENDO, 1937

      Aojia crassa RESSER and ENDO, 1937

      Aojia (?) *carinata* RESSER and ENDO, 1937

      Aojia quadrata RESSER and ENDO, 1937

      Aojia (?) *vilis* RESSER and ENDO, 1937

      Aojia puctata RESSER and ENDO, 1937

      Aojia aigawaensis ENDO, 1937

      Aojia depressa ENDO, 1937

      Aojia reflexa ENDO, 1944

      Aojia angustata ENDO, 1944

      Aojia divergens ENDO, 1944

      Aojia (?) *triangulata* ENDO, 1944

Recently CHU (1959) suggested for *Aojia tumida* its being an immature form of *Metanomocarella*. On account of the narrow straight transversal frontal rim and vaulted oval glabella with pronounced oblique posterior furrows *Lisania* (?) *belenus* (WALCOTT, 1913) may be better located in *Menocephalites* than *Lisania*. RESSER (1942) referred *tellus* to *Lisania* and *biston* and *undata* to *Aojia*. The first of the three species is so ill-preserved that its generic position is hardly determinable. Nevertheless it is certain that its frontal area of the cranidium is evidently too large for *Lisania*. As noted elsewhere (1935), it is certainly very close to *Annamitia*. The two other species are by no means typical of either *Aojia* or *Lisania*, because a narrow space appears to be present between the glabella and frontal furrow.

Lisania alala in fig. 19a, on pl. 15 (WALCOTT, 1913) is quite different from the cranidium in fig. 19 which must be the holotype of the species. The glabella protruded into the frontal rim and the facial sutures convergent forward from the eyes are two distinctive features of the former for which a new name, *Lisania convergens*, is proposed.

Lisania alala, s. str. constitutes a morphic group with *Aojia spinosa* and *A.*

longispina, all having a tapering glabella and a nuchal spine. ENDO (1944) synonymized *luna* and *yentaiensis* with *spinosa* and splitted *pechiliensis* into *spinosa* and *reflecta*. The proposal of *reflecta* is, however, invalidated because of the inclusion of *pechiliensis* whose holotype has never been selected.

Lisania hsuchiachuangensis has no spine on the neck ring but a median node. It differs from *bura* and probably *agonius*, *fracta*, *depressa* and *carinata*. They have all similar tapering glabellae, but the axial carination is very distinct in the last.

Aojia divergens represents a sole example of the glabella forwardly expanding. In *ajax*, *rectangularis*, *quadrata*, *vilis*, *angustata* and *pechiliensis* or *reflexa* the glabella has parallel sides. The frontal furrow is unusually obscure in *ajax*, while the frontal rim is extraordinarily narrow in *angustata*. Therefore the reference of the two species to this genus is not warranted.

L. (?) *ajax* is a Kushanian species which is allied to another Kushanian species, *Aojia* (?) *triangulata*.

Aojia crassa is founded on a pygidium which well agrees with *Lisania* sp. indet, in fig. 20, pl. 15 (WALCOTT, 1913).

Finally, *Proasaphiscus quadrilateralis* RESSER and ENDO, 1937, is, insofar as one can see on the cranidium, not a *Proasaphiscus*, but a *Lisania*.

Distribution:—Middle Cambrian or from Mapanian to Kushanian (?), but most thrived in Taitzuan ; Liaoning, Shantung and Shansi.

Genus *Chuangiopsis* SIVOV, 1955

1955.   *Chuangiopsis* SIVOV, in KHALAFIN'S, *Atlas, Vol. 1*, p. 140.

Type-species:—*Chuangiopsis sibirica* (SIVOV), (Text-figs. 6c–d).

The author noted the resemblance of this genus with *Bernicella* FRED. 1949, in size and general outline of the cranidium, broad cheeks and depressed frontal rim, and the difference in the more conical glabella, stronger glabellar furrows, larger eyes and more distinct eye-ridges. The pygidium of *C. sibirica* is almost thrice broader than long, equally trilobed and a few segmented and has a narrow depressed border. The pygidium is unknown of *Bernicella*, but *Cheilocephalus* BERKEY, 1898, with which *Bernicella* is synonymized (LOCHMAN-BALK, 1959), has the pygidium much longer and quite different from that of *Chuangiopsis*.

Beside the type-species two additional species are known by the names of *C. batiaeforme* and *C. speciosa*. They are all small trilobites whose cranidia are no more than 4 mm. in length. The generic name suggests the alliance of *Chuangiopsis* with *Chuangia*, but *Chuangia* is usually much larger and has a trapezoidal glabella which reaches to the raised and straight anterior rim. No depressed border is present either on the cephalon or the pygidium.

Distribution:—Upper Cambrian of West Siberia.

Subfamily Ordosiinae Lu, 1954

This group of trilobites are different from the Pagodiinae primarily in the preglabellar fosse or/and the mesial thickening of the frontal border.   In the associated pygidium the marginal border is more developed than that of the Pagodiinae.

Distribution:—Middle and Upper Cambrian; Eastern Asia.

Genus *Ordosia* Lu, 1954

1954.   *Ordosia* Lu, *Acta Pal. Sinica, Vol. 2*, p. 435.
1957.   *Ordosia* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 274.
1959.   *Ordosia* Lochman-Balk, in *Treatise on Invert. Pal. O-1*, p. 315.

Type-species:—*Ordosia fimbricauda* Lu, 1954, (Text-figs. 6m-n).

Remarks:—This microtrilobite agrees with *Taitzuia* in most essential characters, but is different in the relatively short glabella, three pairs of oblique furrows, short occipital spine, prominent frontal rim, with shallow concavity and especially in the strong preglabellar fosse as seen in *Blackwelderia sinensis*. Insofar as can be judged from the cranidium, this genus may be a derivative from *Taitzuia*-like trilobites.

The associated pygidium is well characterized by its relatively long outline, narrow multisegmented axis, double furrows on the pleural lobes and the broad border which is concave and inclined inward to the deep marginal furrow.   This genus looks more apart from the Pagodiinae in the pygidium than the cranidium.

Distribution:—Kushanian; Inner Mongolia.

Genus *Taitzuia* Resser and Endo, 1937

1935.   *Taitzuia* Resser and Endo in Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 90.
1937.   *Taitzuia* Resser and Endo, *Manchurian Sci. Mus. Bull. 1*, p. 292.
1959.   *Taitzuia* Lochman-Balk, in *Treatise on Invert. Pal. O-1*, p. 331.

Type-species:—*Taitzuia insueta* Resser and Endo, 1937.

Diagnosis:—Cranidium subtrapezoidal; glabella rectangular; lateral furrows obsolete; occipital ring thickened mesially and carrying a median node; fixed cheek moderate in breadth; eyes medium sized and located at mid-length; frontal border thick, straight, transversal; facial sutures subparallel in front of eyes.

Remarks:—The type species is represented by an imperfect cranidium, but the concept of the genus can be obtained fairly well with supplement of *Taitzuia quadrata* Chang, 1959, (Text-figs. 6a-b), of which is known not only the cranidium, but also the pygidium.   The associated pygidium of this species is fairly long and has pleural and interpleural furrows like *Ordosia*.   The marginal rim is, however, narrow and straight.

This genus was correctly referred to the Pagodiidae by LOCHMAN-BALK, but distinct from the genera of the Pagodiinae in the thicker convex transversal frontal border, large rectangular unfurrowed glabella and somewhat convergent anterior sutures and some other aspects. The marginal and dorsal furrows are confluent in front of the glabella where they form a profound fosse as seen in *Ordosia*. The frontal rim is not so prominent as in *Ordosia*, although it may be thick. The lateral furrows are more obsolete in this genus than in *Ordosia*. The associated pygidium is more rounded and the marginal border narrower in this genus.

Damesella puteolata ENDO, 1937, is probably a *Taitzuia* (KOBAYASHI, 1941). Among the three additional species from the Taitzuan (ENDO, 1944), *T. glabella*'s cranidium may be too narrow for *Taitzuia*. The swollen frontal rim and other aspects of *T. liaotungensis* are suggestive of *Lorenzella* for it. The large quadrate glabella, narrow fixed cheek and pronounced preglabellar depression exclude *T. granulata* from *Taitzuia*.

Taitzuia triangulata ENDO, 1937, (text-fig. 6j), from the late Upper Cambrian must be eliminated from this genus by its more or less trigonal cranidium, conical glabella, distinct oblique lateral furrows, narrow fixed cheeks and frontal rim which is not so strongly reflected upward as in *Taitzuia*. It is probably a derivative from *Kaolishania*. Its test is densely granulated.

Distribution:—Taitzuian of South Manchuria.

Genus *Poshania* CHANG, 1959

1957.   *Poshania* CHANG, *Acta Pal. Sinica, Vol. 5, No. 1*, p. 31, (nom. nud.)
1959.   *Poshania* CHANG, *Ibid. Vol. 7, No. 3*, pp. 200, 221.

Type-species:—*Poshania poshanensis* CHANG, 1959; (text-figs. 6f–g).

Similar to *Taitzuia*, but the frontal rim is thickened at the median part where the marginal groove is suddenly bent back. This marginal furrow is separated from the dorsal furrow by a very narrow transverse ridge which must be a relic of the convex frontal limb.

The cranidium is intimate to that of *Peichiashania*, below mentioned, but the lateral furrows are obsolete and the eyes smaller. The preglabellar ridge is such a characteristic which is rare to see in other trilobites.

Distribution:—Taitzuan; Shantung.

Genus *Peichiashania* CHANG, 1959

1957.   *Peichiashania* CHANG, *Acta Pal. Sinica, Vol. 5, No. 1*, p. 31, (only type-species designated).
1959.   *Peichiashania* CHANG, *Ibid. Vol. 7, No. 3*, p. 223.

Type-species:—*Eymekops rectangularis* ENDO, 1937, (text-fig. 6e).

Remarks:—The type species was compared with *Eymekops hermias* by CHANG, quoting that " *Peichiashania* has proportionately a longer cranidium, longer rectangular glabella, large palpebral lobe, relatively short postero-lateral limb and

relatively narrow frontal border." The absence of the frontal limb avoids the confusion of this genus with *Eymekops*.

In the thick border which is produced back to the glabella and in the large posterior eyes which are each provided with an oblique eye-ridge, the genus agrees with *Lichengia*. Its chief distinction from *Lichengia* lies in the truncato-conical slender outline of the glabella which is provided with three pairs of lateral furrows and a short nuchal spine on the occipital ring. It is probable that *Lichengia* was derived from this genus by the lateral expansion of the glabella which was especially exaggerated in the posterior part.

Distribution:—Daizanian; South Manchuria. The type locality of the type-species is Paichiashan, in Wuhutsui basin, Liaoning, (ENDO, 1937).

Genus *Lichengia* KOBAYASHI, 1942

1942. *Lichengia* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 18*, p. 297.
1959. *Lichengia* LOCHMAN-BALK, *Treatise on Invert. Pal. 0–1*, p. 323.

Type-species:—*Lichengia onigawara* KOBAYASHI, 1942, i.e. *Prosaukia brizo* (WAL-COTT) by SUN, 1935, (text-figs. 6k–l).

"The broad glabella with its remarkably expanded posterior portion, distinct oblique eye-ridge and very thick frontal border, and the pygidium of subtra-pezoidal outline with a stout axial lobe highly elevated above the pleural parts are important characteristics."

It is probable that such a cranidium was derived from Daizanian *Peichia-shania* or the like by the lateral expansion of the glabella, particularly in its posterior part and the reduction of the palpebral lobes. The pygidium is unknown of *Peichiashania*. The associated pygidium of *Lichengia onigawara* is quite different from all others of the Ordosiinae in the broad outline and the developement of the depressed posterior brim. However, if the brim is overlooked, it becomes much closer to those of *Poshania* and *Ordosia*.

Distribution:—Fengshanian; Shansi.

Order Ptychopariida SWINNERTON, 1915

Family Conocoryphidae ANGELIN, 1854

This is a typical Atlantic family, but a few genera occur in the Asiatic continent. Among them *Bailiella* is most extensive, occurring in Kashmir, High Tonkin, Korea, North China, South Manchuria and Eastern Siberia. In Kashmir it is accompanied by *Conocoryphe* (?) (REED, 1934). In Eastern Siberia it is found together with *Ctenocephalus* in the early Middle Cambrian; mediaeval and late Middle Cambrian strata yield *Meneviella* and *Dasometopus* respectively (TCHER-NYSHEVA, 1953).

Genus *Bailiella* MATTHEW, 1885

Bailiella angusta KOBAYASHI, new species

Plate XIX, Figure 18.

Description:—Cranidium subtrapezoidal, about two-thirds as long as broad; glabella a little narrower than cheeks and the former tapers forward more rapidly than the latter; dorsal furrow deep; lateral furrows very obscure; occipital furrow distinct; neither pseudo-ocular ridge nor nerve-like lines discernible on cheeks; frontal border nearly as thick as frontal limb; lateral margin almost straight or only slightly convex outward.

Observation and comparison:—This species is represented by a solitary cranidium which, however, reveals the characteristic features of this genus. As indicated by its asymmetrical outline, the cranidium is deformed by diagonal compression, with the result it is found that the breadth of the cranidium is reduced to some extent. In addition, an obtuse ridge was accidentally produced along the axis of the glabella whereas lateral furrows were obliterated out of the glabella.

In the long outline of the cranidium this species resembles *Bailiella teres* (Grönwall), *B. longifrons* (Cobbold) and *B. cobboldi* Resser, the last of which is known not only from England, but also from Eastern Siberia (Tchernysheva, 1953). It agrees, however, with *B. lantonoisi* (Mansuy) in many other aspects. At a glance the glabella looks very slender and the frontal limb short relative to the frontal border, if compared with *lantonoisi* or *B. ulrichi* Resser and Endo (1937). The cephalon is broader and the glabella much narrower in *B. fragtengensis* (Reed) and *B. sejuncta* (Reed) from Kashmir (1934).

Occurrence:—Dark geen micaceous slate at Sho 16. The slate is a member of the lowest Taiki formation.

Bailiella lantonoisi (Mansuy)

Plate XXI, Figures 1–10.

1916.   *Conocoryphe lantonoisi* Mansuy, *Mém. du Serv. géol. de l'Indochine*, Vol. 5, Fasc. 1, p. 30, pl. 4, figs. 6a–g; pl. 5, fig. 3.

1924.   *Conocoryphe lantonoisi* Hayasaka, *Jour. Geogr. Tokyo. Vol. 35*, p. 209, (listed).

1931.   *Conocoryphe ulrichi* Resser and Endo in Endo's, *Cambrian in Iwanami Lecture Ser.*, *Geol. Pal.* p. 54, figs. 5–8.

1935.   *Conocoryphe lantonoisi* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 218, pl. 23, figs. 13–14.

1937.   *Bailiella ulrichi* Resser and Endo, *Manchurian Sci. Mus. Bull. Vol. 1*, p. 193, pl. 41, figs. 5–8; pl. 42; pl. 59, fig. 21.

1938.   *Bailiella lantonoisi* Resser, *Smithson. Misc. Coll. Vol. 97*, p. 27.

1938.   *Bailiella ulrichi* Resser, *Ibid. Vol. 97*, p. 27.

1953.   *Tangshihella ulrichi* Hupé, *Ann. de Pal. tom. 39*, p. 131.

Description:—Dorsal shield elongately ovate, its length and breadth being in a ratio of about 4 : 3. Cephalon exclusive of spines nearly semicircular, occupying about a third the length of shield, and surrounded by a narrow border; glabella truncato-conical, a little shorter than three-fourths of cephalic length; its basal breadth less than a third of cephalon; dorsal and occipital furrows deep; neck ring not much thickened mesially. Marginal suture runs across antero-lateral part of marginal border, then extends down along its inner

margin and at length it is abruptly bent inward at genal angle.

Thorax composed of 14 segments in adult; axial lobe as wide as a fourth of thorax in anterior, but narrows to a fifth of thorax in posterior part; lateral end of pleura subtriangular.

Pygidium almost as long as a third of thorax; its length corresponds to about a half of breadth; axis composed of 4 rings and a terminal lobe and pleural lobe of four ribs; marginal border narrow.

Observation and comparison:—When RESSER and ENDO proposed *Bailiella ulrichi*, they overlooked *Conocoryphe lantonoisi* with which it should be compared. Well preserved specimens from Indochina, North Korea and South Manchuria facilitate one to make a precise comparison. In a specimen from Kojang or Kojo (1935, pl. 23, fig. 13) the glabella is unusually narrow and conical, but in another (fig. 14) it is remarkably truncated in front. The cephala in figs. 7 and 8 in this volume were procured from the same locality, but have the glabella which agrees better with RESSER and ENDO's from Yentai and Hualien-chai, South Manchuria, in size and outline of the glabella. Three pairs of lateral furrows are obscure in fig. 8, but clearly impressed in fig. 7. Such a difference can also be seen among the cephala of their plate 42.

On the glabella there is generally a blunt keel, although its strength is different to some extent. A median tubercle is occasionally met with on an occipital ring near its posterior margin. The so-called pseudo-ocular ridge is clearly seen in some cranidia. The specimen in fig. 9 shows numerous fine nerve-like lines which are branching off from the ridge.

Fine punctation is seen on some cranidia whose tests are well preserved. The doublure is, insofar as can be judged from detached cheeks, extended for a short distance inward from the inner margin of the free cheek on the dorsal side. The doublure of the pygidium appears to narrow toward the posterior.

A small hypostoma (Fig. 4) from Shihtsutzu is parallel-sided in the middle portion, slightly expanded in posterior and laterally protruded into a narrow wing in anterior.

Ontogeny:—Carapaces in various stages of growth are found in green sandstone (loc. m₅) at a cliff of Shihtsutzu. If *Peronopsis rakuroensis* is excluded, there is no other fossil but this species in the sandstone. Therefore the reference of immature forms to this species is quite warranted.

An external mould of an anaprotaspid, 0.55 mm. long and 0.4 mm. broad (Fig. 1) is subcircular and most expanded a little anterior to the mid-length; axis half as broad as cheek, cylindrical, quinqui-segmented, expanded at frontal lobe and abruptly narrowing near the rear end of the fifth lobe.

A cephalon probably of the metaprotaspid stage (Fig. 2) is 0.85 mm. long and 1 mm. wide. It is well rounded but truncated behind; its glabella narrower than a third of cephalon and divided into five lobes; palpebral ridge extending from the base of the frontal lobe to the lateral margin of the cephalon; occipital ring distinctly marked off from the rest by a strong furrow and thickened in the middle.

Another cephalon (Fig. 3) is of the meraspid stage and appears subtra-

pezoidal, but its outline is intraceable in its whole circumference. It has a distinct marginal rim which may be protruded into a genal spine.

An early holaspid cranidium, 1.5 mm. long and about 2.8 mm. broad (Fig. 6) is different from the full maturity in the narrow, but long and less conical glabella which is separated from the frontal border by a small depression. It possesses a distinct pseudo-ocular ridge.

A small immature pygidium, 0.6 mm. long and 0.85 mm. wide (Fig. 5) reveals a shallow posterior sinuation. The axis is composed of 5 rings and a terminal lobe; pleural and interpleural furrows are equally distinct and number 7 or 8 in total.

Occurrence:—The illustrated specimens were procured partly from a cliff adjacently to the east of Shihtsutzu (石咀子) village, east of Liaoyang, Liaoning and partly from a locality 4 km. ENE of Kojang or Kojo (古場), North Korea. The species is widely distributed in the Tangshih stage in the Taitzuho valley, South Manchuria, Ch'osan or Sosan area, North Korea and Yunnan-Tonkin border. In the Changpoung series on the border this species occurs at Tienfong in two horizons. It is accompanied by *Acrothele* cfr. *eryx* WALCOTT and *Eymekops sinensis* (MANSUY) in the upper horizon and *Manchuriella* (*Hundwarella*) sp., in the lower horizon (MANSUY, 1916, KOBAYASHI, 1944) *A. eryx* is a typical member of the Tangshihan fauna.

Family Solenopleuridae ANGELIN, 1854

In 1935 I have classified the Solenopleuridae into the Solenopleurinae and Dokimocephalinae and included *Solenopleura, Lonchocephalus, Solenoparia, Menocephalites, Hystricurus, Crusoia, Levisia, Onchonotus, Clelandia, Ischyrotoma, Solenopleurella, Pesaia* and (?) *Sao* in the former and *Dokimocephalus, Burnetia, Iddingsia* and provisionally *Elkia* and *Acrocephalites* in the latter subfamily. Later in 1942, RESSER erected Burnetiidae, but now it is synonymized with the Dokimocephalidae.

Lately HUPÉ (1953) proposed Solenopariidae, Menocephalinae of Solenopleuridae, Acrocephalitidae, Lonchocephalidae and Hystricuridae and combined 15 families into the Solenopleuroidae. Recently the Bathyuridae, Raymondinidae, Isocolidae, three proetid families (Tornquistiidae, Dimeropygidae and Otarionidae) and two marjumid-families (Talbotinidae and Punctulariidae) which had been brought into the Solenopleuroidae were eliminated from the superfamily, but at the same time the Agraulidae, Avoninidae, Catillicephalidae and Kingstoniidae were added to the Solenopleuracea (HARRINGTON et al. 1959). It can, however, hardly be overlooked that, while the Solenopleuridae are intimate to the ptychopariids, these agraulid-families are so close to the Plethopletidae that they would consitute a distinct group in which the preglabellar area is generally simple and gently convex and not wire-like. The glabellar aspect of the Catillicephalidae is quite different from the Conocoryphacean type of HENNINGSMOEN (1951) and better agrees with the Zacanthoidacean than the Redlichiacean type.

In the Solenopleurinae the cephalon is stongly convex; test often granulose or pustulate; glabella ovate or subconical, strongly convex, sometimes vaulted; glabellar furrows often obsolete, but diagonal posterior furrows are commonly well marked; eyes medium sized; occipital furrow usually profound.
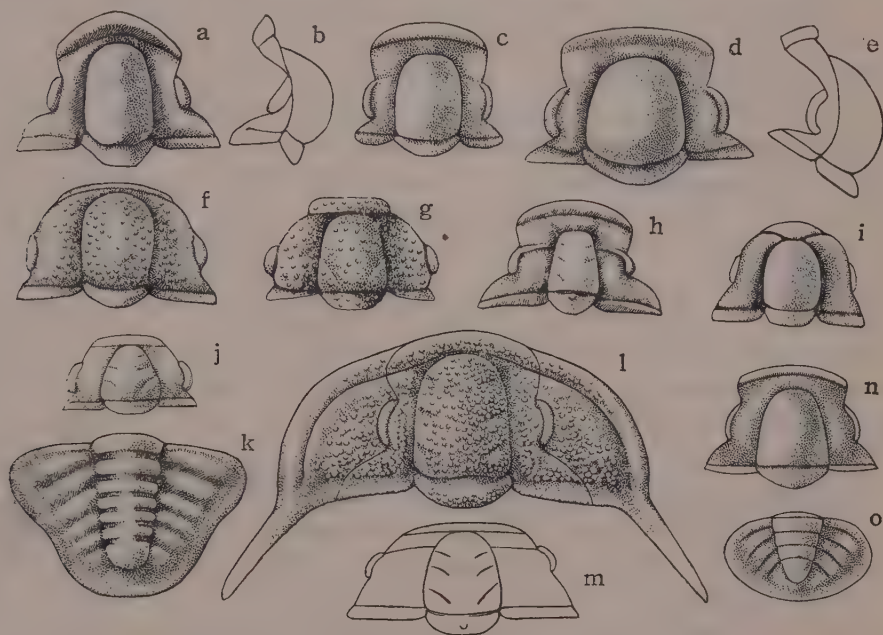
Figure 7.   Solenopleuridae and similar genera

a–b.   *Aidarella vigilans* LERMONTOVA
c.   *Obrucheviaspis inornatus* IVSHIN
d–e.   *Urbanaspis notabilis* IVSHIN
f.   *Paramenocephalites admeta* (WALCOTT)
g.   *Menocephalites acanthus* (WALCOTT)
h.   " *Parasolenopleura* " *subconsocialis* POLETAYEVA
i.   *Onchonotellus abnomis* IVSHIN
j–k.   *Eilura typa* RESSER and ENDO
l.   *Pseudosolenopleura kotoi* (KOBAYASHI)
m.   *Liaotungia puteata* RESSER and ENDO
n–o.   *Solenoparia toxeus* (WALCOTT)

Asthenopsis levior WHITEHOUSE in the Middle Cambrian of Australia has 14 segments in thorax.   *Yorkella australis* (WOODWARD) from the Lower Cambrian Parara limestome of South Australia, (DALLY, 1957), as noted elsewhere (1935) bears solenopleurid-aspect, although the eyes are very large.

In Eastern Asia the Solenopleurinae are not well represented, but Chang-shanian *Pseudosolenopleura kotoi* (KOBAYASHI) is a member of the subfamily.

Parasolenopleura POLETAYEVA, 1955, based on early Middle Cambrian *Para-solenopleura subconsocialis* POLETAYEVA, 1955, (text-fig. 7h), from the Shorie Mountains, West Siberia is homonymous with *Parasolenopleura* WESTERGÅRD, 1953, founded on *Calymene aculeata* ANGELIN, 1851.   Therefore the earlier one is valid.

POLETAYEVA's looks a ptychoparioid, instead of a solenopleurid, having a broad cranidium, narrow truncato-conical glabella, relatively wide fixed cheeks crossed by distinct eye-ridges, fairly long eyes at the mid-length of the cranidium and an elevated frontal rim as long as a frontal limb. Lateral furrows of the glabella are said to vary in strength greatly among species; neck ring thickened mesially and carrying a median tubercle; dorsal furrows pitted at antero-lateral angles whence blunt grooves appear to extend, limiting the preglabellar area. The axial and pleural lobes of the pygidium are 4- and 3-segmented respectively; pleural and interpleural furrows present; marginal rim narrow. It is remarkable that *P. subconsocialis* is closely allied to *Ptychoparia consocialis* REED (1910) from the Middle Cambrian of Spiti.

Subfamily Solenopleurinae ANGELIN, 1854

Genus *Pseudosolenopleura* SUN, 1935

1935. *Pseudosolenopleura* SUN, *Pal. Sinica, Ser. B, Vol. 7, Fasc. 2*, p. 17.
1953. *Pseudosolenopleura* HUPÉ, *Ann. de Pal. tom. 39*, p. 146.

Type-species:—*Solenopleura kotoi* KOBAYASHI, 1933, (text-fig. 7 l).

Diagnosis:—Solenopleuridae with strongly vaulted, long, tapering glabella, three oblique lateral furrows, narrow fixed cheeks, fairly large, elevated palpebral lobe, relatively broad free cheeks and genal spines. Palpebral ridge absent; test granulose.

Distribution:—Early Upper Cambrian; Liaoning and Shantung.

Subfamily Solenopariinae HUPÉ, 1953

This includes solenopleurids having strongly convex cranidium, ovate or oblong glabella, obsolete lateral furrows, narrow fixed cheeks, medium sized eyes at mid-length; eye-ridges weak or absent; frontal rim strongly convex, detached from the glabella by a narrow frontal limb; anterior facial sutures only slightly divergent; test smooth or finely granulate. The associated pygidium of *Solenoparia* is paucisegmented and provided with depressed narrow border.

Urbanaspis IVSHIN, 1956 and *Obrutcheviaspis* IVSHIN, 1956 from the Middle Cambrian of Kazakstan and *Aidarella* LERMONTOVA, 1951, from the Upper Cambrian of Kazakstan resemble *Solenoparia* in one or the other important character. All of them have the strongly convex glabella and distinctly elevated frontal rim separated from the glabella by a narrow frontal limb and their lateral furrows are well obsolete. *Urbanaspis*, (text-figs. 7d–e), however, differs from *Solenoparia* in the larger glabella and rudimentary eye-ridges. The cranidium is narrower and the glabella nearly parallel-sided in *Obrucheviaspis* (text-fig. 7c). In *Aidarella*, (text-figs. 7a–b), the glabella becomes longer, eyes smaller and the frontal rim strongly arcuate.

Distribution:—Middle and Upper Cambrian; Asia.

Genus *Solenoparia* Kobayashi, 1935

1935. *Solenoparia* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 259.
1953. *Solenoparia* Hupé, *Ann. de Pal. Tom. 39*, p. 135.
1957. *Solenoparia* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 271.
1959. *Solenoparia* Lochman-Balk, in *Treatise on Invert. Pal. O–1*, p. 309.

Type-species:—*Ptychoparia* (*Liostracus*) *toxeus* Walcott, 1905, (text-figs. 7n–o).

Remarks:—In this genus the ocular ridge is extremely weak or indiscernible. The associated pygidium is paucisegmented and surrounded by a smooth border; interpleural furrows generally obsolete.

Walcott has described 5 species of *Solenopleura* from the Cambrian of China among which *agno, beroe, chalcon* and *intermedia* belong to *Solenoparia*, but *pauperata* is a member of *Menocephalites*. Resser and Endo (1937) splitted *beroe* into three species. Namely, they restricted the species to the Upper Cambrian form in fig. 17 on pl. 17 (Walcott, 1913) and erected *Solenoparia planifrons* and *S. puteata* respectively for the Middle Cambrian forms in figs. 14 and 14a.

Solenopleura nodosa Sun appears to include two species. One has a large oval glabella and the other possesses a relatively small oblong glabella. Their frontal rims are remarkably straight like that of *Menocephalites acanthus*, but the rim is clearly separated from the glabella by the frontal limb. The former on which *nodosa* seems to be founded may be placed in *Solenoparia*. The latter specimen of *nodosa* probably indicates an unnamed form of *Paramenocephalites*.

Among Resser and Endo's species of *Solenoparia, puteata, planifrons, hemicycla, affinis, angustilimbata* and probably *quadrata, kuantungensis, tersa* and *subsphaerica* are retained in this genus. According to Endo (1944), however, *puteata* and *beroe* (pars) belong to an identical species with *planifrons*. Their *triangularis, inaii, taitzuensis, salebrosa, bigranosa, catinus, sphaerica, luna, sobyosiensis, tangshihensis* and probably *hsipiensis* agree better with *Menocephalites* than *Solenoparia*.

In the type-species of *Solenoparia* the frontal rim is rectangularly truncated on the lateral ends, but in *distincta* and some other forms including *S. agno* and *S.* (?) *deprati* from South Korea have the sutures remarkably intramarginal on the frontal border. Such forms may be distinguished from *Solenoparia* s. str., when a thorough study can be made with a more material.

Finally *Solenoparia hsinkiangense* Troedsson, (1937), from the Upper Cambrian of East Tienshan was compared by the author with *S. beroe* and *S. agno*, but quite different from them in the subcylindrical relatively narrow glabella, broad fixed cheek and especially in the presence of peculiar arcuate ridge in front of the glabella. Unfortunately the specimen is weathered, but it is probable that the species represents a genus distinct from *Solenoparia*.

There are however, several species in Siberia which are referable to *Solenoparia* (1943). *Solenopleura djainensis* Lermontova, 1940, is one of them and *Solenopleura ferovae* Lerm. in Tchernysheva, 1953, is another. They have 12

segments in thorax.

Distribution:—Middle and Upper Cambrian ; Shantung, Liaoning, South Korea, Siberia and probably Australasia (Öpik et al. 1957).

Solenoparia laevis Kobayashi, new species

Plate XIX. Figures 14a–b, 15, 16.

Description:—Cranidium subtrapezoidal and strongly inflated ; glabella long, conical, rounded in front, strongly covex, devoid of lateral furrows, but occipital ring clearly delimited by a deep furrow ; fixed cheek at base a little wider than glabella, eyes at mid-length of cranidium, medium in size ; eye-ridge absent ; frontal rim thick, convex, distinctly bent up to the middle ; frontal groove profound, confluent with deep dorsal furrows to form a lenticular depression in front of glabella ; facial sutures nearly diagonal behind eyes ; these anterior to eyes subparallel, but abruptly converge on marginal border ; test smooth.

Observation:—A pygidium (fig. 16) from the same locality is subtrigonal and very much inflated ; marginal border narrow and horizontal. The axial lobe is as broad as a pleural lobe in front and subcylindrical, but abruptly rounded at rear and highly elevated above pleural lobes ; 4 rings countable in anterior half, but furrows become obsolete in posterior ; likewise, only 3 or 4 anterior ribs distinct on pleural lobe.

An associated hypostoma has a long elliptical central body surrounded by a narrow rim ; anterior border straight and alate on two sides.

Comparison:—The strong convexity of the cephalon, longiconic glabella, narrow and well rounded frontal rim and lenticular depression are distinctive characteristics of this species. The associated pygidium resembles those of *Manchuriella macar* (Walcott) and *Solenoparia* (?) *deprati* Kobayashi. The axial lobe is, however, narrower in *macar*. The pygidium of *deprati* is trigonal in outline, while the arcuate latetal margin gives a rounded aspect on this pygidium.

Occurrence:—*Solenoparia* zone ; Sho 10.

Subfamily Menocephalitinae Kobayashi, new subfamily

1953.   Menocephalinae Hupé, *Ann. de Pal. Tom. 39*, p. 138.

Because *Menocephalus* Owen is an invalid name, the term, Menocephalinae, is unfortunately untenable.

The Menocephalitinae include small to medium sized solenopleurids having broad cranidia ; glabella nearly as wide as a fixed cheek, both strongly convex ; eyes moderate in size ; eye-ridges absent or weak, if present ; preglabellar area absent or very narrow, if present ; anterior rim straight and transversal ; anterior facial sutures convergent.

Distribution:—Middle Cambrian ; Eastern Asia.

Genus *Menocephalites* KOBAYASHI, 1935

1913.   *Menocephalus* WALCOTT, (non OWEN, 1852) *Cambrian Faunas of China*, p. 172.
1935.   *Menocephalites* KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2,*
p. 267.
1942.   *Taitzuia* RESSER (non RESSER and ENDO, 1937), *Smithson. Misc. Coll. Vol. 101,*
No. 15, p. 53.
1953.   *Menocephalites* HUPÉ, *Ann. de Pal. Tom. 39,* p. 138.

Type-species:—*Menocephalus acanthus* WALCOTT, 1905, (text-fig. 7g).

Remarks:—This is a clear-cut genus typifying the subfamily. It has neither
a preglabellar field nor an ocular ridge; glabella strongly vaulted, ovate in
outline; fixed cheek somewhat narrower than glabella; eyes medium in size,
at mid-length or a little posterior; preocular sutures convergent; test granulated.
Lateral furrows vary in strength, but one or two pairs are usually discernible.
In the type-species the posterior furrow is very pronounced. The marginal
border is undefined on its pygidium.

RESSER confused *Taitzuia* with this genus, but its distinction from *Taitzuia*
can be made easily by its strongly convex ovate glabella, presence of oblique
furrows and so forth. Test is generally granulose in this genus, while only
fine granules emerge in *Taitzuia* under high magnifer.

Solenopleura pauperata WALCOTT, 1906, is a representative in Shansi, *Soleno-
paria inaii* RESSER and ENDO and some other Taitzuan species of *Solenoparia* are
located more properly at *Menocephalites*.

Distribution:—Middle Cmabrian; Shantung, Shansi and Liaoning.

Genus *Paramenocephalites* KOBAYASHI, new genus

Type-species:—*Menocephaus admeta* WALCOTT, 1905, (textfig. 7f).

Remarks:—This genus differs from the proceding primarily in the glabellar
outline which is parallel-sided or nearly so and secondarily in the complete
effacement of lateral furrows. The frontal rim is very slender, if compared
with that of *Menoceaphalites*. In the type-species a narrow interspace is present
between the rim and glabella, but absent in *M. acis* WALCOTT which belongs also
to this genus. Their tests have either scattered granules or minute tubercles.

Taitzuian *Damesella nitida* RESSER and ENDO is a *Paramenocephalites*.

Distribution:—Middle Cambrian; Shantung and Liaoning.

Genus *Liaotungia* RESSER and ENDO, 1937

1937.   *Liaotungia* RESSER and ENDO, *Manchurian Sci. Mus. Bull. 1,* p. 236.
1953.   *Liaotungia* HUPÉ, *Ann. de Pal. Tom. 39,* p. 138.

Type-species:—*Liaotungia puteata* RESSER and ENDO, 1937, (text-fig. 7m).

Diagnosis:—Cranidium broad trapezoidal; glabella semi-ovate, subcarinate,
with 2 to 4 pairs of oblique furrows; eyes at a little anterior; eye-ridge rudi-
mentary or absent; test finely pustulose under magnifer.

Remarks:—The generic diagnosis is given here, because the authors gave

simply the comparison of the genus with *Solenoparia* and *Bailiella*.

WALCOTT's *Menocephalus* (?) sp. indt. from the Middle Cambrian of Yen-chuang, Shantung (1906, 1913) is undoubtedly a member of this genus.

Distribution :—Middle Cambrian of Liaotung and Shantung.

Genus *Eilura* RESSER and ENDO, 1937

1937. *Eilura* RESSER and ENDO, *Manch. Sci. Museum. Bull. 1*, p. 217.
1953. *Eilura* HUPÉ, *Ann. de Pal. Tom. 39*, p. 120.

Type-species :—*Eilura typa* RESSER and ENDO, 1937, (text-figs. 7j–k).

Remarks :—The genus was proposed for a triangular pygidium with sharply down-turned lateral borders. Later ENDO (1944) referred a cranidium to the same species which looks very much like *Menocephalites*, but the glabella is quite triangular in outline and provided with three pairs of deep oblique lateral furrows. Palpebral lobes are relatively large and located a little posterior to the middle of the cranidium and united with a weak oblique palpebral ridge ; frontal border short, straight and transversal ; facial sutures running straight inward and forward from the eyes. Test finely granulose.

It resembles *Liaotungia puteata* in many aspects, but in that species the fixed cheek is as wide as the glabella at the base, palpebral lobe rather small and the glabella provided with four pairs of shallow lateral furrows. Further, "the rim flat and deflected upward from the frontal furrow", while the rim appears convex and wire-like in *Eilura typa*.

Eilura quadrata ENDO, 1937, from the Mapanian of Chinchiachengtzu which has a large quadrate glabella and concave preglabellar area is not congeneric with *E. typa*.

Distribution :—Taitzuan ; the Taitzuho valley, Liaoning.

Subfamily Hystricurinae HUPÉ, 1953

Levisia WALCOTT, 1911, founded on *Agraulos agenor* WALCOTT, 1905, from the Taitzuan of Shantung has a strong convex cranidium, tumid oval glabella and fairly broad convex frontal border. Its posterior furrows are weak and oblique and eye-ridges absent. It agrees with *Onchonotellus abnormis* IVSHIN, 1956, (text-fig. 7i), from the Upper Cambrian of Kazakstan in many character-istics, but the glabella is relatively large, the frontal rim much narrower, strongly convex and bent up mesially and the circumglabellar furrows are extraordinarily profound in *Onchonotellus abnormis*. Its thorax is composed of 9 segments. The pygidium is said small, elongated laterally, semi-circular in outline and devoid of marginal rim ; rachis elevated and composed of 4 rings and a terminal lobe.

Mataniella SIVOV, 1955, is known of the incomplete cranidium of *M. escha-roida* SIVOV from the Upper Cambrian of the Salair Mountains, West Siberia, the major part of which is occupied by a convex subsphaeric glabella ; basal side-lobe marked off by weak posterior lateral furrow ; frontal rim wire-like,

arcuate, separated from glabella by incised marginal furrow; eyes small, at mid-length; fixed cheek narrow, but a triangular postero-lateral limb is fairly large. It is similar to *Onchonotus* and *Matania*, but this genus has no pre-glabellar area, while the posterior furrow is present on the glabella.

Beside these, *Onchonotus* occurs in South Korea and probably in Central China (1951). *Hystricurus* is represented in South Korea by some species.
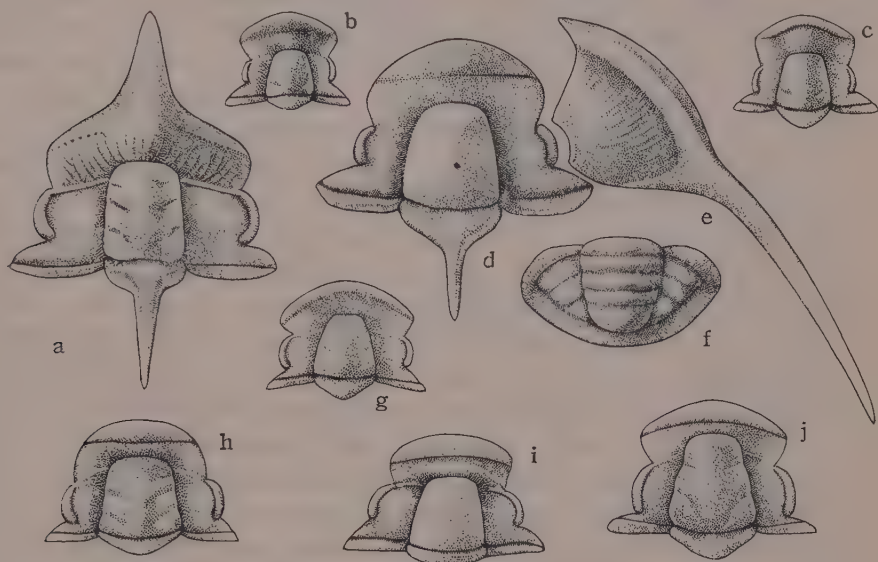
Figure 8. Dokimocephalidae and similar genera
- a. *Aldanaspis punctatus* LERMONTOVA
- b. *Kujandaspis kujandensis* IVSHIN
- c. *Acrocephalaspis fidus* IVSHIN
- d–f. *Paracrocephalites robustus* (LERMONTOVA)
- g. *Kujandina taskudukensis* IVSHIN
- h. *Kassinius kassini* IVSHIN
- i. *Pesaia exsculpta* WALCOTT and RESSER
- j. *Tatulaspis princeps* IVSHIN

Family Dokimocephalidae KOBAYASHI, 1935

Subfamily Acrocephalitinae HUPÉ, 1953

This was first proposed by the author as a family to include *Acrocephalites, Aldanaspis, Acrocephalina* and *Proampyx*. Then, POULSEN (1959) accepted it as a subfamily of the Solenopleuridae and beside *Acrocephalites*, he referred *Acrocephalapsis, Aldanaspis, Cliffia, Pesaia*, and probably *Paracrocephalites* (*Arctaspis* LERMONTOVA, non HEINTZ) and *Acrocephalina* to it.

The distinction of the Dokimocephalidae by LOCHMAN, 1959, from the Acrocephalitinae is, however, not clear enough to draw a sharp boundary between them. In looking through the known dokimocephalids and acrocephalitids, there are of course some differences between the latter or Eurasiatic and the former or North American group. Namely, it is seen as the general tendency in the

former group that the frontal rim is strongly convex, the median boss well developed and the glabella truncated behind it. In the latter group, on the other hand, the glabella has generally a rounded anterior margin and the frontal limb and rim are simply and gently convex. The trilobites have flourished in Eurasia in the Middle and Upper Cambrian times, but in North America they are restricted to the Upper Cambrian. Thus the morphic differences are related to the specio-temporal development of the trilobites. Therefore the two groups are recongnized as two subfamilies of the Dokimocephalidae.

The following genera are here tentatively referred to the Acrocephalitinae:

1. *Acrocephalites* Wallerius, 1895. Middle and Upper Cambrian; Eurasia.
2. ? *Proampyx* Frech, 1897. Middle Cambrian; Eurasia.
3. ? *Pesaia* Walcott and Resser, 1924. Upper Cambrian; Novaya Zemlya, (text-fig. 8i).
4. ? *Acrocephalina* Troedsson, 1937. Upper Cambrian; Tienshan and Korea.
5. ? *Aldanaspis* Lermontova, 1940. Middle Cambrian; Siberia, (text-fig. 8a).
6. *Kassinius* Ivshin, 1953. Middle Cambrian; Kazakstan, (text-fig. 8h).
7. ? *Paracrocephalites* Poulsen, 1954. Upper Cambrian; Siberia, (text-figs. 8d-f).
8. *Neoacrocephalites* Sivov, 1955. Upper Cambrian; West Siberia.
9. ? *Abacanopleura* Sivov, 1955. Upper Cambrian of West Siberia.
10. *Acrocephalaspis* Ivshin, 1956. Upper Cambrian; Kazakstan, (text-fig. 8c).
11. *Kujandaspis* Ivshin, 1956. Upper Cambrian; Kazakstan, (text-fig. 8b).
12. *Kujandina* Ivshin, 1956. Upper Cambrian; Kazakstan, (text-fig. 8g).
13. *Tatulaspis* Ivshin, 1956. Upper Cambrian; Kazakstan, (text-fig. 8j).

Westergård (1953) is of opinion that *Proampyx* is synonymous with *Agraulos*. It is probable that, combined with *Aldanaspis*, *Acrocephalina* and *Paracrocephalites*, it constitutes a distinct group of trilobites which belongs to the Dokimocephalidae or the Agraulidae.

Pesaia as compared with *Euloma* by the authors, bears similarities to *Euloma*, *Eulomella* and *Paraeuloma*. In the Eulominae, however, two or three pairs of short lateral furrows are always present and the marginal groove is often pitted (1955. I have previously noted its resemblance with *Solenopleurella* (1935), but the presence of the frontal limb as large as the frontal rim is the distinction from that genus. In Treatise (1959) it is referred to the Acrocephalitinae, but its cranidium is much broader than those of *Acrocephalites* and *Paracrocephalites*. The broad cranidium, truncato-conical glabella and fairly broad fixed cheek crossed by a transverse eye-ridge of *Pesaia*, all reveal ptychoparioid appearance. Like *Alokistocare* it has a preglabellar boss, but the frontal limb is on the whole distinctly convex and has no radial striae. *Pesaia* and probably *Cliffia* appear to be located in the Ptychopariidae, close to the Eulominae, but not in that subfamily.

Family Agraulidae Raymond, 1913

In Eastern Asia there are many trilobites which were primarily considered members of *Agraulos* and later of *Inouyia*. The type species of *Inouyia*, is

Agraulos (?) *capax* WALCOTT which is quite different from all other species of *Inouyia* or *Argaulos* of Eastern Asia in the broad cranidium and narrow cylindrical glabella.   These species having narrower cranidia and truncato-conical glabellae are certainly closer to *Agraulos* than *Inouyia*.   They were reclassified in 1935 and splitted into *Lorenzella*, *Megagraulos* and *Metagraulos*.

Megagraulos (text-figs. 9o–p) and *Metagraulos* (text-fig. 9m) are intimate, but the ocular ridge is present and the marginal furrow discernible in the former, while neither the ridge nor the furrow remains in the latter.   Furthermore the latter never grows so large as the former.

Tangshihlingia CHU, 1959, is according to the author, a small Kushanian agraulid of low convexity having a nearly flat preglabellar field.   It resembles *Metagraulos* but the glabella is not so convex, neck ring of equal breadth, and eyes are located more posteriorly.   *T. subtriangulata* CHU from Yentai, Liaoning is monotypic.

In *Lorenzella* the marginal furrow as well as lateral furrows may be present or absent, but if present, they are rudimentary.   The most significant characteristic of this genus lies in the strong convexity of the preglabellar area which is swelling up in form of a boss.   On this account it fits in *Inouyia* s. str., but they are totally different in the forms of the cranidium and glabella.

Megagraulos, *Metagraulos* and *Lorenzella* agree with *Agraulos* in the simply convex preglabellar area or the weakness of the marginal furrow.   In the typical forms of *Agraulos* eyes are much smaller and opposed in the anterior of the glabella.   In the size and position of the eyes these Asiatic genera of the Agraulidae agree better with *Proampyx acuminatus* (ANGELIN) than *Agraulos ceticephalus* (BARRANDE), although the fronal limb and rim are generally more differentiated and pre- and post-cranial axial spine are often well developed in the Swedish and Siberian forms which were referred to *Proampyx*.

On that occasion I employed Agraulinae for the group term of these genera and combined this subfamily with the Ellisocephalinae and Kingstoninae in the Ellipsocephalidae, noting however, that the *Agraulos* and *Ellipsocephalus* groups need to be distinguished in the higher rank.   The two groups are referred to the separate orders in Treatise (1959).   The Agraulinae and Kingstoniinae remain in the Agraulidae.

Previously I have included seven genera in the Agraulinae, but *Proliostracus* is better to be removed into the Ptychoparid group.   As noted already, *Proampyx* is either a member of the Acrocephalitidae or a member of an unnamed group. *Chondroparia* in which the cranidium is very broad and the frontal limb and rim are distinctly divided, must be excluded from the Agraulinae.

Here *Paragraulos*, *Yabeia*, *Chondragraulos*, *Shirakiella* and some other Asiatic genera are added to the subfamily.

In *Paragraulos* LU, 1941, which was already referred to the Agraulidae by HUPÉ (1953) and LU (1957) the marginal furrow, lateral glabellar furrows and eye-ridges are all fairly distinct.   *P. kummingensis* LU (text-figs. 9c d), from the Lower Cambrian of Yunnan is the type-species.   It is undoubtedly congeneric with *Ptychoparia titiana* WALCOTT, 1905, (text-fig. 9b), from the lower Middle
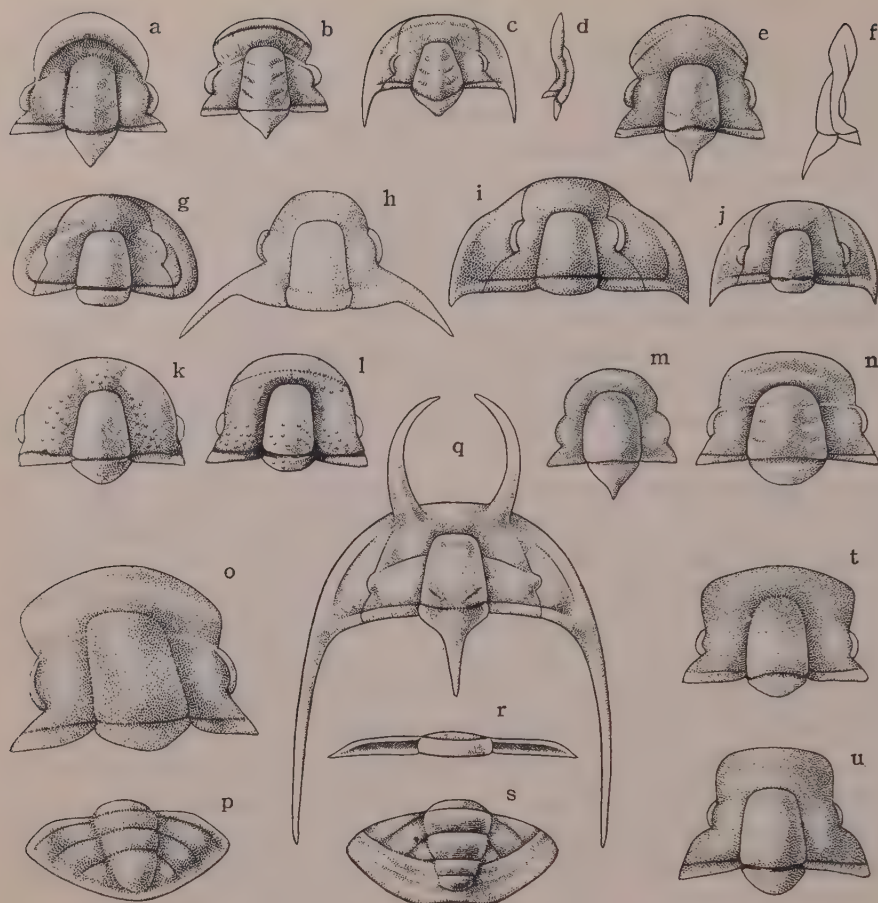
Figure 9. Agraulidae

a.   *Inouyellaspis expectans* IVSHIN
b.   *Paragraulos titiana* (WALCOTT)
c–d. *Paragraulos kummingensis* LU
e–f. *Lorenzella abaris* (WALCOTT)
g.   *Latilorenzella divi* (WALCOTT)
h.   *Wongia triangulata* SUN
i.   *Shirakiella elongata* KOBAYASHI
j.   *Cyclolorenzella quadrata* (KOBAYASHI)
k.   *Cyclolorenzella convexa* (RESSER and ENDO)
l.   *Chondragraulos minussensis* LERMONTOVA
m.   *Metagraulos nitida* (WALCOTT)
n.   *Semicyclocephalus terminalis* IVSHIN
o–p. *Megagraulos coreanicus* KOBAYASHI
q–s. *Diceratocephalus armatus* LU
t.   *Semisphaerocephalus normalis* IVSHIN
u.   *Yabeia laevigata* RESSER and ENDO

Cambrian of Shantung, for which RESSER proposed *Inouyops*, in 1942.   Naturally the later one is superflous.

Inouyellaspis IVSHIN, 1953, (text-fig. 9a), is an aberrant genus in the early Middle Cambrian of Kazakstan having a peculiar profound lunate fosse behind a frontal border which is elevated in form of an arcuate crest ; glabella also highly elevated, slowly tapering, truncated in front, incised by three pairs of weak lateral furrows ; fixed cheek nearly as wide as glabella ; eyes opposed at the center of glabella ; eye-ridge oblique.   This would be a highly specialized off-shoot from *Paragraulos*.

Chondragraulos LERMONTOVA, 1940, (text-fig. 9l), is widely distributed in the early Middle Cambrian in Siberia and Central Asia.   Its cranidium is small, relatively wide, somewhat quadrate or trapezoidal, but well rounded, glabella subcylindrical, but slightly tapering and truncated in front, unfurrowed, and outlined by extraordinarily incised dorsal furrows ; neck ring thickened mesially ; eye located far posteriorly for the family ; fixed cheek nearly as wide as glabella at this point, crossed by an oblique eye-ridge ; frontal limb and rim faintly divided by a very shallow furrow.

Yabeia RESSER and ENDO, 1937, (text-fig. 9u), was considered a member of the Solenopleuridae by HUPÉ (1953) and of the Marjumiidae by LOCHMAN-BALK (1959), but it is an agraulid as the joint authors compared its type-species with *Agraulos ceticephalus*.   Insofar as the cranidium is concerned, it is undeniable that *Yabeia* is extremely close to *Metagraulos*.   *Yabeia laevigata* RESSER and ENDO and *Agraulos nitida* WALCOTT are respectively the type-species of *Yabeia* and *Metagraulos*. Seeing that the two species are almost connected by *Agraulos abrota* WALCOTT, I think it quite probable that *Yabeia* is a synonym of *Metagraulos*.   It is a question whether the combination of spiniferous triangular pygidia with *Yabeia laevigata* and *Lorenzella rotundata* is veritable or not.

When I proposed *Shirakiella*, I considered it to be a ptychaspid whose lateral glabellar furrows are effaced.   HUPÉ (1955) erected the Shirakiellidae and in Treatise (1959) the family is placed in the Illaenuracea.   In the relatively anterior position of the eyes and the greater postero-lateral limb of the fixed cheek *Shirakiella* agrees with certain ptychaspids, but otherwise it looks much more like agraulids, and especially close to *Yabeia*, i. e. *Metagraulos*.

It is a remarkable fact that *Shirakiella* is allied to *Wongia triangulata* SUN, 1924, (text-fig. 9h), except for the prolongation of the postero-lateral limb into a spine and the preglabellar boss.   *Wongia* is most probably a derivative of *Lorenzella* by high specialization which took place in many branches in the Kushan stage.   Whether or not, it is really related to Dresbachian *Avonina* is still a question.   It is, however, certain that Franconian *Xenocheilos* which is combined with these two genera in the Avaronidae in Treatise, is by no means a later member of the same evolutional branch with *Wongia*, because *Xenocheilos* reveals much more primitive aspects than *Wongia*.

Diceratocephalus LU, 1954, must be another derivative of *Lorenzella*.   As it is so highly specialized, the author proposed a new family for it.   It is, however, not much deviated from *Lorenzella*, if a pair of precranial spines are ignored.

In the convergence of the anterior facial sutures *Diceratocephalus* agrees with *Wongia*. It is further noteworthy that the pygidium of *Diceratocephalus* is, though somewhat sinuated in posterior, essentially same as that of *Megagraulos*. The degeneration of the eyes and their posterior position are very distinctive from other agraulids. Therefore the Diceratocephalinae are accepted here as a subfamily of the Agraulidae.

Finally, *Semicyclocephalus* Ivshin, 1953, from the Middle Cambrian of Kazakstan has the cranidium relatively broad, if compared with most other agraulids, but it may be included in the Agraulidae. Because *Agraulos regularis* Walcott, 1906, has been an isolated species among oriental agraulids, I am particularly interested to find its similarities with *Semicyclocephalus terminalis* Ivshin (text-fig. 9n), in the broad cranidium and glabella, course of the lateral furrows, transverse eye-ridge, preglabellar swelling and other aspects.

Semicyclocephalus is intimately related to *Semisphaerocephalus* Ivshin, 1953, (text-fig. 9t). Both of them occur together in the *Anomocare-Phoidagnostus* zone of Kazakstan, but the effacement is one step more advanced in the latter than the former. I have previously grouped the effaced agraulids in the Kingstoninae to which Ivshin added these two genera, but it is a question that either *Wongia* or *Semisphaerocephalus* is ancestral to *Kingstonia* or American Kingstoninae.

Subfamily Agraulinae Raymond, 1913

Genus *Lorenzella* Kobayashi, 1935

1935. *Lorenzella* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2,* p. 201, 209.
1953. *Lorenzella* Hupé, *Ann. de Pal. Tom. 39,* p. 151.
1957. *Lorenzella* Lu, *Index Fossils of China, Invert. Vol. 3,* p. 272.
1959. *Lorenzella* Howell, in *Treatise on Invert. Pal. 0-1,* p. 247.

Type-species:—*Agraulos abaris* Walcott, 1905, (text-figs. 9e–f).

The genus has been understood so comprehensively that it comprises the wide morphic variation from *abaris* to *Lorenzella* (?) *convexa* Resser and Endo. The type species of *Lorenzella* is very close to *Paragraulos titiana*. They are similar to each other in the outline of the glabella and cranidium, but the marginal furrow is rudimentary and the frontal limb and rim are combined to reveal a simple convexity in *abaris*. The preglabellar median boss is more developed in *melia* and *inflata* than *abaris*, but all of these three species have the anterior facial sutures divergent. Lateral furrows are impressed in some strength in their glabellae. Therefore other species of *Lorenzella* whose anterior sutures are convergent, if not parallel and the lateral furrows effaced out of the glabella, are here segregated from *Lorenzella*.

Lorenzella (?) *taitzuensis* Endo, 1937, as well as *Agraulos dryas* Walcott, 1905, to which the Endo's species was made comparison, belong to neither *Lorenzella* nor the Agraulidae, because they have cylindrical glabella which is detached from the frontal border by a depressed frontal limb, although it is narrow.

It is difficult to give any comment on *Lorenzella lilia* Endo, 1944, because the illustration is obscure and the description brief. However, the specimen in fig. 7, on pl. 9 which has a broad cranidium, convex lunáte frontal rim separated from the glabella by a narrow depressed frontal limb is certainly more similar to *Solenoparia* than *Lorenzella*. It is specifically distinct from the cranidium in fig. 8, which is more quadrate and has a more cylindrical glabella. As it was procured from the late Upper Cambrian, it might be a *Shirakiella*.

Distribution :—Middle Cambrian ; Shansi and Shantung.

Genus *Cyclolorenzella* Kobayashi, new genus

Type-species :—*Lorenzella quadrata* Kŏbayashi, (text-fig. 9j).

Diagnosis :—Small strongly convex agraulids whose cranidium is subquadrate, subtrapezoidal or subtriangular, but usually well rounded ; glabella truncato-conical, outlined by profound circum-glabellar furrow ; lateral furrows effaced ; occipital furrow generally persistent ; neck ring often thickened mesially, and sometimes produced into a median spine ; fixed cheeks and preglabellar area not much different from the breadth of the glabella at its base ; eyes small or medium in size, located at about the mid-length of glabella ; eye-ridge week or obsolete ; preglabellar boss often bounded by a diagonal furrow on each side or strongly swelling up ; anterior facial sutures more commonly convergent than parallel to each other ; posterior ones short and steeply slant.

Pygidium broad ; axis one-third or one-fourth as wide as pygidium, about 5-segmented ; marginal border narrow or undeveloped.

Test smooth or ganulose.

Remarks :—This genus includes the following species :

Agraulos acalle Walcott, 1905
Agraulos armata Walcott, 1906
Agraulos tonkinensis Mansuy, 1915
Lorenzella rotundata Resser and Endo, 1937
Lorenzella (?) *convexa* Resser and Endo, 1937, (text-fig. 9k)
Lorenzella (?) *ogurai* Resser and Endo, 1937
Lorenzella parabola Lu, 1957
Lorenzella pustulosa Chu, 1959
Lorenzella subcylindrica Chu, 1959
Lorenzella yentaiensis Chu, 1959
Lorenzella kushanensis Chu, 1959

It is probable that some of them will be ignored by synonymy by a careful comparison. There are however, very distinct species. The occipital spine is well developed in *tonkinensis* and *armata* in the latter of which the occipital furrow is effaced. The cranidium of *convexa* is unusually well rounded and its test pustulose. The free cheek of *quadrata* is ending posteriorly at a short spine. The associated pygidium of this species is somewhat longer than those of *parabola, yentaiensis* and *subcylindrica*.

Distribution :—Flourished in Kushanian, but appeared already in Taitzuan ;

Liaoning, Shantung, Shansi, Korea and Yunnan-Tonkin border.

Genus *Latilorenzella* Kobayashi, new genus

Type-species:—*Agraulos divi* Walcott, 1905, (text-fig. 9g).

Similar to *Cyclolorenzella*, but the cranidium is broader, eye-ridge present but genal spine absent.

Agraulos regularis Walcott, 1906, belongs to this genus. In the outline of the cranidium, it looks similar to *Semicyclocephalus*, but in the convexity and especially in the development of the preglabellar boss it is more allied to *Cyclolorenzella* and *Lorenzella*.

Distribution:—Middle Cambrian (Taitzuan ?) ; Shantung and Shansi.

Genus *Shirakiella* Kobayashi, 1935

(i. e. *Mansuyella* Endo, 1937)

1935. *Shirakiella* Kobayashi, *Jour. Fac., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 321.
1937. *Mansuyella* Endo, *Manchurian Sci. Mus. Bull. 1*, p. 353.
1953. *Mansuyella* Hupé, *Ann. de Pal. Tom. 39*, p. 161.
1955. *Shirakiella* Hupé, *Ibid. Tom. 41*, p. 196.
1957. *Shirakiella* Lu, *Index Fossils of China, Invert. Vol. 3*. p. 286.
1959. *Mansuyella* Poulsen, in *Treatise on Invert. Pal. 0–1*, p. 364.

Type-species:—*Shirakiella elongata* Kobayashi, 1935, (text-fig. 9i).

Remarks:—*Mansuyiella* is synonymized with *Shirakiella* by the reason that the type-species of the former is *Coosia tokunagai* Kobayashi, 1931, which belongs to the latter genus. The subtriangular pygidium with a pair of spines, which is almost identical with a pygidium of *Kaolishaniella transita* (fig. 4, pl. III, Sun, 1935) was combined with the cranidium into *Mansuyella tokunagai* by Endo. This combination is however, a question.

Changshania truncata Sun, 1935, is quite probably a member of this genus. Resser (1942) placed *Anomocarella carme* Walcott, 1905, in *Shirakiella*, but its long preglabellar area excludes it from the genus. It is certainly more allied to *Kazelia*.

Distribution:—Daizanian of South Korea and Liaoning. As pointed out already (1935), *tokunagai* is not a Kushanian member.

Shirakiella (?) sp.

Plate XX, Figure 12.

A pygidium found associated with *Shirakiella elongata* as well as *S. laticonvexa* is very broad ; its axial lobe short, conical and divided into three rings and a small terminal lobe ; pleural lobe divided into three ribs by deep furrows, each having an interpleural furrow on the top ; marginal border quite broad and concave.

Occurrence:—Daizanian at Sho 16.

Subfamily Diceratocephalinae Lu, 1954

Genus *Diceratocephalus* Lu, 1954

1954. *Diceratocephalus*, Lu, *Acta. Pal. Sinica, Vol. 2, No. 4*, p. 431.
1957. *Diceratocephalus* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 272.

Type-species:—*Diceratocephalus armatus* Lu, 1954, (text-figs. 9q–s).

In addition to the above species this genus includes *Diceratocephalus latifrons* Lu, 1954, and the cranidium of *Blackwelderia* (?) *cornuta* Endo, 1937, which I once referred to *Lorenzella* (1942). It is particularly interesting to see in the last species the initial stage of the precranial spine-growth.

Distribution:—Kushan stage of Liaoning (Penhsihfu, Yentai and Chinchiach-engtzu).

Family Asaphiscidae Raymond, 1925

This family is characterized on the cephalon by the conical glabella rounded or truncated in front, eyes of medium or small size, usual presence of frontal limb and rim of subequal length. The relative size of the pygidium to the cephalon varies to a great extent. The depressed marginal border on the pygidium is not very broad, but generally well defined on the inner side.

Subfamily Liopariinae Kobayashi, new subfamily

The replacement of *Yokusenia* Kobayashi, 1935, by *Lioparia* Lorenz, 1906, causes me to propose the above new name for the Yokuseninae Kobayashi, 1935, which is represented in Eastern Asia by *Inouyella*, *Kokuria* and probably *Mapania* and *Changshanocephalus*, beside *Lioparia*.

Lioparia (text-fig. 10d) has the truncato-conical glabella with lateral furrows, medium sized eyes located fairly anteriorly and connected with the glabella by eye-ridges, long concave preglabellar field crossed by an axial elevation and large postero-lateral limb of the fixed cheek. The free cheek has a narrow convex platform, broad concave border and short genal spine. Anterior facial suture is semi-circular.

Kokuria (text-fig. 10b) differs from *Lioparia* in the unfurrowed glabella and narrow preglabellar field. The two genera are united by *Kokuria obsoleta* which agrees with *Kokuria typa* in these characters, but palpebral lobes are much smaller and located anteriorly like *Lioparia*.

Lioparia is Changshanian whereas *Kokuria* is Daizanian. The two genera occur in South Korea in a same section. Therefore the latter can be a derivative from the former. *Inouyella* could be collaterally ancestral to *Lioparia*, because it is a Taitzuan genus.

Inouyella (text-fig. 8c) has a much broader cranidium than that of *Lioparia*. The difference depends chiefly upon the relatively broader fixed cheeks at eyes and shorter preglabellar area. Like in *Lioparia* this area is concave, but in

Inouyella it is bounded by a pair of diagonal furrows and has a median boss. The vestige of the boss is recongnized in the area of *Lioparia*, but it is completely gone in *Kokuria*.
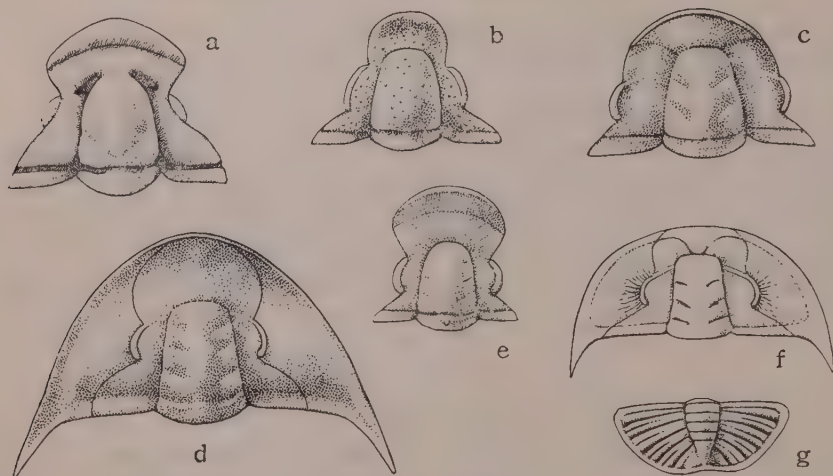
Figure 10.   Liopariinae

a.   *Metisaspina anomalis* SIVOV
b.   *Kokuria typa* KOBAYASHI
c.   *Inouyella peiensis* RESSER and ENDO
d.   *Lioparia vulgaris* (KOBAYASHI)
e.   *Changshanocephalus reedi* SUN
f–g. *Mapania striata* RESSER and ENDO

Mapania RESSER and ENDO in KOBAYASHI, 1935, is still older, occurring in the Mapan formation. It is founded on *Mapania striata* RESSER and ENDO, i. e. *Ptychoparia typa* WALCOTT, non DAMES, (text-figs. 10f-g), which is characterized primarily by the posterior projection of the frontal rim as far as it reaches the glabella. The glabella is truncato-conical; lateral furrows distinct; fixed cheek of moderate breadth; eyes medium sized; eye-ridge distinct; free cheek fairly broad and striated radially; genal spine short; anterior sutures subparallel; rostral plate a third as wide as the preglabellar field. Pygidium broad; axis narrow; pleural and interpleural furrows distinct; marginal border narrow; posterior margin sinuated. *Mapania* is probably an early off-shoot, rather than the incipient genus of this subfamily.

Beside these there are some trilobites in Siberia which are probably referable to this subfamily.

Orloviella typa SIVOV and *O. truncata* SIVOV from the early Upper Cambrian of ,West Siberia are closely allied to *Orlovia arctica* from Novaya Zemlya as indicated by the agreement of the general aspect of the cranidium, but *Orloviella elandiensis* SIVOV from the late Middle Cambrian (?) of Altai as well as *O. conica* SIVOV from the early Upper Cambrian of Salair are different from them, notably in the position of the eyes in far anterior of the cranidium and their small size. Accordingly the fixed cheeks are developed behind the eyes into large triangular limbs as seen in *Lioparia*. In the preglabellar as well as pre-

ocular area *conica* and *elandiensis* agree with *Changshanocephalus reedi* Sun, insofar as the outline and convexity are concerned.   The area is, however, smaller and the furrows on the glabella are obsolete in these Siberian species.

Metisapina Sivov, 1955, (text-fig. 10a), is an aberrant genus in the early Upper Cambrian of west Siberia, but bears some similarieites with *O. conica* and *Lioparia* as a genus.   The cranidium is large, strongly convex; glabella long, conical, defined by incised dorsal furrows on lateral sides and abruptly narrowing in anterior where the furrows are unusually excavated; a pair of lateral furrows diagonal and deep on the posterior of the glabella; occipital furrow deep; occipital ring thickened mesially; eyes probably small and close to the antero-lateral angle of the glabella; fixed cheeks behind them large, triangular, nearly as wide as the glabella at the base; frontal limb slightly longer than frontal rim; anterior facial suture somewhat sigmoidal.

Genus *Lioparia* Lorenz, 1906

1906. *Lioparia* Lorenz, *Zeitschr. deutsch. geol. Gesell. Bd. 58*, p. 73.
1935. *Yokusenia* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, 2-4-2*, p. 247.
1953. *Yokusenia* Hupé, *Ann. de Pal. Tom. 39*, p. 120.
1957. *Lioparia* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 269.
1959. *Lioparia* Howell, in *Treatise on Invert. Pal. 0-1*, p. 288.

Type-species:—*Anomocare latelimbatum* Dames, 1883.

Remarks:—As pointed out already in 1937, *Yokusenia* Kobayashi is a synonym of *Lioparia* Lorenz, because *Yokusenia vulgaris*, the type of the former, (text-fig. 10d) is congeneric with the type-species of the latter.

In *latelimbatum* the frontal border is separated from the frontal limb, while in *vulgaris* the two parts form a simply concave area except for an obscure axial ridge which is somewhat expanded in front.   Three pairs of lateral furrows are well impressed in the glabella of the latter whereas they are obsolete in the former.   The preglabellar field is very long in Lorenz's *Lioparia latelimbatum* for which I proposed *L. lorenzi* in 1938.   In this species the field exceeds the glabella in length and three furrows on the glabella are transversal, instead of oblique in *vulgaris*.

It is fairly certain that *Crepicephalus orientalis* Endo, 1937, and *Changshania orbiculata* Endo, 1937, (cranidium only) belong to this genus.   It is, however, a question that *Yokusenia manchoukuoensis* Endo, 1944, (i. e. *Y. manchuriensis* Endo, 1944, on plate) and his *Y. granulosa* can be in the fold of this genus, because they appear to have concave frontal limbs and the test is granulose in the last, while it is smooth in all others.

Distribution:—This is a leading fossil in the early Upper Cambrian of Shantung, Liaoning and Korea.

Lioparia latelimbata (Dames)

1883. *Anomocare latelimbalum* Dames, in Richthofen's, *China Bd. 4*, p. 14, pl. 2, figs. 9-10, only.

1913. *Anomocare latelimbatum* DAMES in WALCOTT, *Research in China, Vol. 3*, pl. 18, fig. 2. only.
1937. *Lioparia latelimbatum* KOBAYASHI, *Jour. Geol. Soc. Tokyo, Japan. Vol. 44*, p. 428, pl. 17, fig. 5.

Here is summarized the tangled history of taxonomy attached to *Anomocare latelimbatum*. Through the type revision (1937) it was ascertained that DAMES' species involves three distinct species and genera. Therefore the form in figs. 9-10 was selected for the type of the species so as to accord with DAMES' original diagnosis. His specimen in fig. 13 may be a free cheek of *Chuangia* sp. *Saimachia damesi*, new gen. and sp. was erected for the form in fig. 16 and 16a. As mentioned above, *A. latelimbatum* is congeneric with *Yokusenia vulgaris* as well as *L. lorenzi* in 1938, i. e. LORENZ's *Lioparia latelimbata*. WALCOTT's *Anomocare latelimbatum* with which I figured the specific concept of *latelimbatum* and accordingly of *Lioparia* in my publication in 1935, is evidently distinct from either *Yokusenia vulgaris* or *Lioparia latelimbata*, s. str. Therefore *Lioparella walcotti* n. gen. and sp. was given for WALCOTT's *latelimbatum*.

Occurrence:—Changshanian ; Liaoning.

Lioparia conicula KOBAYASHI, new species

Plate XXI, Figure 15.

Like *L. lorenzi* this has a short glabella which is, however, more prominent, if compared with that of *lorenzi*. The glabella is nearly half as long as the cranidium, truncato-conical in outline, tapering forward fairly abruptly and provided with three pairs of lateral furrows beside an occipitel one. The axial keel is not so significant as in *lorenzi*. This species is quite different from *lorenzi* in the simply concave frontal limb and strongly convex frontal rim which is abruptly thickened toward the axis. In *lorenzi* the rim is relatively narrow and much less convex and the limb reveals concavo-convex curvature behind the rim. The eyes are unpreserved, but appear to be set closer to the glabella and more salient than those of *lorenzi*. The cranidium is on the whole more inflated in this species than in *lorenzi*.

This species can easily be distinguished from *L. latelimbata* by the smaller glabella and well developed preglabellar area.

Occurrence:—*Chuangia* zone at Sho 3.

Genus *Changshanocephalus* SUN, 1935

1935. *Changshanocephalus* SUN, *Pal. Sinica, Sec. B, Vol. 7, Fasc. 2*, p. 40.
1955. *Changshanocephalus* HUPÉ, *Ann. de Pal. Tom. 41*, p. 190.

Type-species:—*Changshanocephalus reedi* SUN, 1935, (text-fig. 10e).
Diagnosis:—Cranidium contracted at large eyes and thence expanded to form a broad concave frontal area ; glabella outlined by deep dorsal furrow, truncato-conical, vaulted up and provided with two or three pairs of weak oblique furrows.

Remarks :—*Yokusenia conica* ENDO, 1944, is typical of this genus, but distinct from the type-species in the much broader glabella and the presence of the eye lines. Judging from the short concave glabella, narrow fixed cheek and large preglabellar concavity *Ptychoparia* (*Proampyx*) *burea* WALCOTT, 1905, is most probably a fragmentary cranidium of this genus rather than *Lioparia* to which RESSER referred (1942). The relatively short frontal area and its swelling up toward the axis are specific characteristics. The glabella is larger and less convex in *Anomocare bergeroni* WALCOTT, 1905, than the precedings, but nevertheless it is a *Changshanocephalus*.

Distribution :—Changshanian ; Shantung and Liaoning.

Family Anomocaridae POULSEN, 1927

Genus *Eymekops* RESSER and ENDO, 1935

1935. *Eymekops* RESSER and ENDO in KOBAYASHI, *Jour. Fac. Sci. Imp. Univ. Tokyo, 2-4-2*, p. 241.
1937. *Eymekops* RESSER and ENDO, *Manchurian Sci. Mus. Bull. 1*, p. 222.
1953. *Eymekops* HUPÉ, *Ann. de Pal. Tom. 39*, p. 119.
1959. *Eymekops* HOWELL, in *Treatise on Invert. Pal. 0-1*, p. 288.

Type-species :—*Anomocarella hermias* WALCOTT.

Remarks :—In erecting *Eymekops* for *A. hermias*, RESSER and ENDO (1937, 44) described 7 other species among which *obsoleta, similis, punctata, reflexa, quadrilateralis* and possibly *granulosa* belong to this genus. On the other hand *Eymekops rectangularis* ENDO from the Daizanian bears little possibility to be *Eymekops*, because it has no frontal limb. *Peichiashania* was erected by CHANG for it. (See page 372).

As discussed elsewhere (1944), *Conokephalina sinensis* MANSUY, 1916, from Tonkin-Yunnan border and *Anomocare hundwarensis* REED, 1934, from Kashmir have the typical cranidia of this genus. They are represented by complete dorsal shields. The former species possesses 13 thoracic segments and its pygidium is small. In the latter the pygidium is much larger and its thorax composed of only 9 segments. REED's *Anomocare* sp. from Spiti (1910) may be still another species of *Eymekops* (1935).

Distribution :—Middle Cambrian ; Eastern, Southeastern and South Asia.

Eymekops expansus (KOBAYASHI)

Plate XIX, Figure 17.

1935. *Lioparia expansus* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, 2-4-2*, p. 240, pl. 19, fig. 13.

Description :—Glabella subquadrate, as long as broad, somewhat narrowing forward and rounded in front, gently convex, gradually elevating toward axis ; anterior latetal furrows almost evanescent ; posterior ones weak and transversal ; occipital one a little stronger ; cccˈpital ring thickened mesially ; eye-band

horizontal, very large, nearly semicircular, but expanded postero-laterally; its anterior end lying in contact with, but its posterior end detached from glabella; fixed cheek at eye half as broad as glabella; preglabellar field dilating forward, its length being half as long as glabella exclusive of neck ring; frontal limb more or less inclined forward and frontal rim convex and elevated; the former evidently broader than the latter; facial suture starting from eye-band at a short distance from glabella, running antero-laterally and cutting frontal rim inside of the lateral extremity of the band; text smooth.

Observation and comparison:—This species has palpebral lobes to be too large for *Lioparella*. At first I thought that the specimen is compressed in the axial trend, but soon its broad outline is found to be original, because lateral and occipital furrows are not more pronounced than usual in the genus. The short glabella and relatively long frontal limb or preglabellar field are quite distinctive of this species.

Occurrence:—*Solenoparia* zone; Sho 10 B.

Eymekops carinata KOBAYASHI, new species

Plate XXI, Figure 9.

The glabella is subquadrate, gently tapering forward, truncated in front and distinctly carinated axially; lateral furrows effaced; occipital furrow shallow; occipital ring carrying a median tubercle; eyes almost as long as glabella exclusive of neck ring, nearly semi-circular, but more expanded in posterior and connected with glabella by a very short ridge; preglabellar area very short; frontal limb and rim subequal in length where the former is depressed and the latter convex and somewhat projected back at the middle; anterior facial sutures divergent forward from sides of the anterior of glabella; test smooth.

This is easily distinguished from *E. expansus* by the relative length of the glabella to the cranidium which is shorter in *E. expansus*. On this account it agrees better with *Anomocarella hermias* which is the type-species of *Eymekops*. In that species, however, the glabella is rounded at front, the preglabellar field larger and the frontal rim neither so elevated nor so clearly defined.

Occurrence:—*Solenoparia* zone at Sho 10.

Family Tsinanidae KOBAYASHI, 1933

As discussed in detail in 1931 and 1935, smooth trilobites are polyphyletic in origin. This family included Upper Cambrian trilobites which are considered to have been drived by effacement from the Asaphiscidae or the family in addition to the Anomocaridae.

Tsinania and *Dictyites* are two important genera in Eastern Asia, most common and extensive in the Fengshanian or late Upper Cambrian. A lengthy revision was made on these genera in 1952. The pygidia of the Tsinanidae are generally entire, but *Tsinania humilis* has a pair of tiny lateral spines.

Dictyella (text-fig. 11f) is another having a short posterior spine.   Its pygidium resembles that of *Tsinania ceres* but has a more triangular outline and a spine which is protruded from the posterior border.   The pygidium of *Dictyella* looks certainly similar to those of *Trigonocera* Ross, 1951 and *Trignocerella* Hintze, 1952, but no asaphid cephalon is found associated with the pygidia of *Dictyella*.

Esseigania (text-fig. 11b) from Northern Siberia closely resembles *Dictyella* but can easily be distinguished from *Dictyites* by the broader glabella, smaller eyes located more posteriorly and the distinctly depressed frontal border.   *Koldiniella* Sivov, 1955, (text-figs. 11i–j), from the early Upper Cambrian of Salair, West Siberia is, according to the author, resembles *Koldinia*, (text-fig. 11c), in the cranidium and pygidium, but in the latter the frontal border is broad, simplified and separated from the frontal rim by an indistinct short furrow and the glabella broader at the base.   Insofar as I can see from the two cranidia in fig. 7a–b, pl. 15, in Khalfin, 1955, the strongly depressed and remarkably flattened frontal border, posterior small eyes, broad glabella and narrow fixed cheeks on the base are all specialities diagnostic of *Esseigania*.   Therefore it is certain that *Koldiniella* is most intimate to *Esseigania*.   The pygidium of *Koldiniella* is broad, convex and distinctly trilobed by deep axial furrow and its axial lobe is relatively broad.
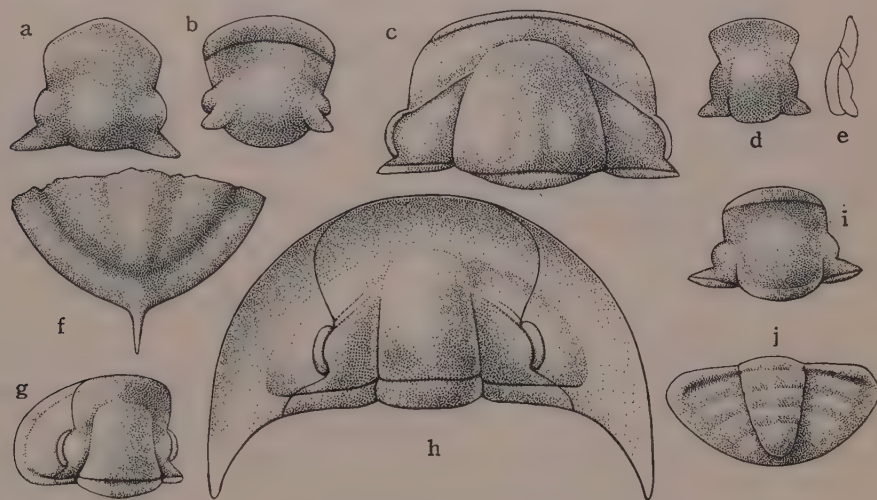
Figure 11. Tsinaniidae
a. *Dictyites dictys* (Walcott)
b. *Esseigania tolli* Kobayashi
c. *Koldinia microphthalma* Kobayashi
d-e. *Jubileia grandifrons* Kobayashi
f. *Dictyella wuhuensis* Kobayashi
g. *Kazelia speciosa* Walcott and Resser
h. *Taipaikia glabra* (Endo)
i-j. *Koldiniella mitella* Sivov

Kazelia Walcott and Resser, 1925, (text-fig. 11g), has the cranidium simply convex like that of *Tsinania*.   Their outline are also similar, but the palpebral lobes larger and located far back in *Kazalia*.   Accordingly the fixed cheek

behind the eye is very small. The glabella faintly outlined by rudimentary dorsal furrows is three-fourths as long as the glabella and subquadrate like that of *Tsinania*. It is, however, gradually tapering forward in *Kazelia*. In this genus the genal spine is absent and the marginal borders well marked on free cheeks become obsolete in front of the glabella.

Finally, *Jubileia*, (text-figs. 11d-e), which is found together with *Glyptagnostus* in western Canada is similar to *Kazelia* in the outline of the cranidum, but different from *Kazelia* in the concavity of the preglabellar field. On this account it agrees better with *Dictyites*, but differs from that genus in the truncato-conical glabella which is slightly but distinctly elevated above the cheeks and the possession of the fairly disinct eye-ridges. It may be intimately related to *Haniwoides*, but the cranidium of *Haniwoides* is evidently more flat.

The reference of *Esseigania*, *Koldiniella*, *Kazelia*, *Jubileia* and *Taipaikia* to this family is still tentative. For the decision one must look for the other parts of their carapaces.

Genus *Tsinania* WALCOTT, 1914

Tsinania canens (WALCOTT)

1952. *Tsinania canens* KOBAYASHI, *Trans. Proc. Pal. Soc. Japan, N. S. No. 5*, p. 150, pl. 13, figs. 1-8, text-fig. 2. (See for synonymic references).

The species is fully described in the paper above cited. The cranidium from Sho 4 is more convex than usual and eyes are relatively large. The outline of the glabella vaugely shown by weak dorsal furrows is unusually long. Therefore this may turn out a new species, if a better material is obtained.

Occurrence:—Fengshanian at Sho 4.

Genus *Taipaikia* KOBAYASHI, new genus

Type-species:—*Paramansuyella glabra* ENDO, 1937.
What is known of this genus is included in the description of the type species. It is distinct from *Mansuyia* in the much shorter glabella, broad concave marginal border, relatively smaller ocular platform and relatively posterior eyes which are connected with the glabella by eye ridges obliquely running across the fairly broad fixed cheeks.

Distribution:—Daizanian; Eastern Asia.

Taipaikia glabra (ENDO)

Plate XXI, Figures 20-21, (?) Plate XX, Figure 18, Text-figure 11h.

1937. *Paramansuyella glabra* ENDO, *Manchurian Sci. Mus. Bul. 1*, p. 358, pl. 69, figs. 21–22.
1952. *Mansuyia* (?) *glabra* KOBAYASHI, *Trans. Proc. Pal. Soc. Japan*, p. 148.

Description:—Cranidium semicircular, but probably with a pair of short spines; glabella conical, gradually tapering forward and unfurrowed; occipital

and dorsal furrows shallow and the latter obsolete in front; fixed cheek relatively broad; eyes of moderate size, posterior to the middle of glabella; eye-ridge narrow, but distinct and very oblique; ocular platform small; marginal brim very broad and concave; facial suture cutting frontal margin at about mid-breadth of fixed cheek; test smooth.

Comparison:—The cranidium and free cheek procured from the same locality enable me to outline the complete cephalon. Its genal spine is, however, unpreserved. The pygidium referred to this species by ENDO is distinctly segmented and looks to me closely allied to *Kaolishaniella*. It is more likely for this genus to have a pygidium more obsolete in segmentation. An imperfect pygidium found in the same bed at Sho 16 is broad, semicircular and gently convex; axial lobe composed of more than 8 rings, occupying a quarter of the pygidium breadth in front and rather abruptly tapers; segmentation quite obscure on pleural lobes.

Incidentally, *Paramansuyella* ENDO, 1937, and *Paramansuyia* ENDO 1939 are, as pointed out already (1952), two synonyma of *Mansuyia* SUN, 1924, em. SUN, 1935.

Occurrence:—Daizanian at Sho 4 and (?) Sho 16 in South Korea; Paichiashan, Liaoning.

Family Ptychaspididae RAYMOND, 1924

Ptychaspids and saukids are so closely related that they consititute two subfamilies of a family. It is, however, a question whether eurekids are equally intimate to them.

Compared to saukids, ptychaspids have the glabella commonly more convex, broader fixed cheeks, and smaller and more anteriorly located eyes; marginal furrow sometimes absent. The difference is greater in the pygidium. In most ptychaspids it is small, subtriangular or semicircular; interpleural furrows weak or obsolete; marginal border narrow or absent. Saukid pygidia are generally subcircular or elliptical; pleural and interpleural furrows distinct; marginal border developed into a wide flat or concave brim.

Subfamily Ptychaspidinae RAYMOND, 1924

This subfamily is represented in Eastern Asia by *Asioptychaspis*, *Changia*, *Quadraticephalus* and *Saukioides*, i. e. *Pseudosaukia* KOBAYASHI, 1951, non RASETTI, 1944. The last is similar to *Changia* and *Quadraticephalus* by the eyes which are longer and opposed at the middle of the glabella. The marginal furrow is distinct on the free cheek. The glabella tapers so slowly forward as that of *Changia*, but the associated pygidium is paucisegmented and has a similar outline to that of *Quadraticephalus*.

Distribution:—Croixan in North America; Fengshanian or late Upper Cambrian of Eastern Asia.

Genus *Asioptychaspis* KOBAYASHI, 1933

1933.   *Asioptychaspis* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 116.
1935.   *Ptychaspis* SUN, (non HALL), *Pal. Sinica, Ser. B, Vol. 7, Fasc. 2*, p. 26,
1942.   *Asioptychaspis* RESSER, *Smithson. Misc. Coll. Vol. 101, No. 15*, p. 6.
1957.   *Ptychaspis* LU, *Index Fossils of China, Invert. Vol. 3*, p. 286.
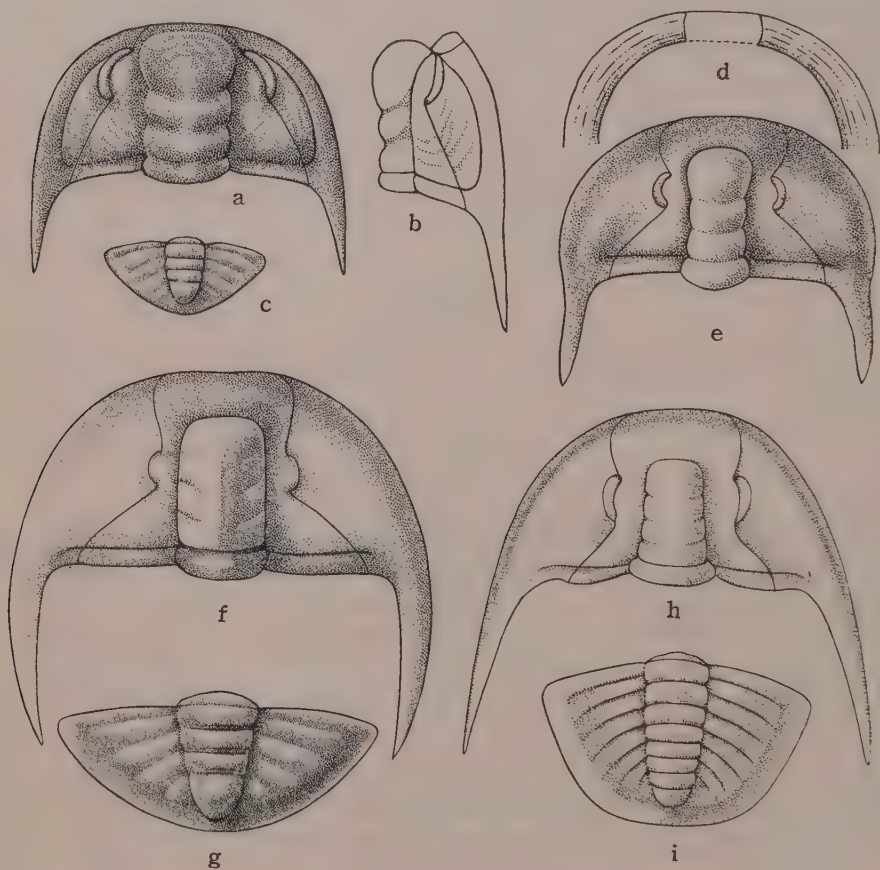
Figure 12.   Ptychaspidinae

a-c.   *Asioptychaspis subglobosa* (GRABAU) in SUN
d-e.   *Quadraticephalus coreanicus* KOBAYASHI
f.   *Quadraticephalus walcotti* SUN
g.   *Quadraticephalus manchuricus* KOBAYASHI
h-i.   *Changia chinensis* SUN

Type-species:—*Ptychaspis ceto* WALCOTT, 1905.
Specific list:—

    Ptychaspis calyce WALCOTT, 1905.

    Ptychaspis cacus WALCOTT, 1905.

    Ptychaspis subglobosa SUN, 1924, (text-figs. 12a-c).

    Asioptychaspis sphaerica KOBAYASHI, 1933.

Ptychaspis brevicus SUN, 1935.

" *Ptychaspis* " *asiatica* RESSER and ENDO, 1937.

" *Ptychaspis* " *sphaerica* RESSER and ENDO, 1937 (i. e. *Asiptychaspis spaerica* KOBAYASHI).

Asioptychaspis chihliensis RESSER, 1942 (i. e. *Asioptychaspis subglobosa* (SUN)).

Remarks:—As pointed out by some authors, *Asioptychaspis* is closely allied to *Ptychaspis*. None of *Asioptychaspis*, however, has such an abruptly tapering conical glabella as seen in *Ptychaspis miniscaensis* (OWEN). It is cylindrical or even expaned forward. In some forms the glabella is extraordinally swollen at the frontal lobe. Furthermore, the eyes are located anteriorly and close to the glabella. Therefore the fixed cheek is much narrower in *Asioptychaspis* than *Ptychaspis*. Because these characteristics are maintained all by *ceto, calyce, subglobosa, sphaerica, shansiensis* and *brevicu*s, the Asiatic ones are appropriate to separate from *Ptychaspis*.

Asioptychaspis is essentially different from the three other genera in the drooping of the frontal border.

Distribution:—Fengshanian ; Shantung, Hopei, Liaoning and Korea.

Genus *Changia* SUN, 1924

1924. *Changia* SUN, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4*, p. 59.
1955. *Changia* HUPÉ, *Ann. de Pal. Tom. 41*, p. 197.
1957. *Changia* LU, *Index Fossils of China, Invert. Vol. 3*, p. 286.
1959. *Changian* LOCHMAN-BALK, in *Treatise on Invert. Pal. 0-1*, p. 320.

Type-species:—*Changia chinensis* SUN, 1924, (text-figs. 12h–i).

Specific list:—

Changia chosensis KOBAYASHI, 1935.

Changia shakuotunensis SUN, 1935.

Remarks:—This genus has the glabella very slender and slightly tapering forward, while it is broadened at the neck ring. The palpebral lobes are fairly large.

These two species agree with the type-species in the large eyes close-set to the middle of the glabella.

Distribution:—Fengshanian ; Shantung, Jehol and South Korea.

Genus *Quadraticephalus* SUN, 1924

1924. *Quadraticephalus* SUN, *Pal. Sinica, Ser. B, Vol. 1, Fasc. 4,* p. 61.
1933. *Quadraticephalus* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 11*, p. 119.
1942. *Quadraticephalus* RESSER (pars), *Smithson. Misc. Coll. Vol. 101, No. 15*, p. 48.
1955. *Quadraticephalus* HUPÉ, *Ann. de Pal. Tom. 41*, p. 197.
1957. *Quadraticephalus* LU, *Index Fossils of China, Invert. Vol. 3*, p. 285.
1959. *Quadraticephalus* LOCHMAN-BALK, in *Treatise on Invert. Pal. 0-1*, p. 322.

Type-species:—*Quadraticephalus walcotti*, SUN, 1924, (text-fig. 11f).

Specific list:—

Ptychaspis calchas Walcott, 1905.

Quadraticephalus (?) *convexus* Sun, 1924.

Quadraticephalus manchuricus Kobayashi, 1933, (text-fig. 12g).

Quadraticephalus pyrus Kobayashi, 1933.

Quadraticephalus teres Resser and Endo in Kobayashi, 1933.

Quadraticephalus quadratus Kobayashi, 1935.

Quadraticephalus elongatus Kobayashi, 1935.

? *Coreanocephalus cylindricus* Kobayashi, 1935.

Quadraticephalus linyuensis Sun, 1935.

Quadraticephalus howelli Sun, 1935.

Ptychaspis shansiensis Sun, 1935.

Ptychaspis (?) *fengshanensis* Sun, 1935.

Quadraticephalus coreanicus Kobayashi, new species.

Remarks:—The outline of the glabella and size of the palpebral lobe vary in *Quadraticeaphalus* to some extent, as seen among these species. The associated pygidium is quite different between *Changia* and *Quadraticephalus*. Namely, it is much longer and has more segments in the former. Resser referred *Anomocare bianos* Walcott, 1905, to *Quadraticephalus*, but it differs from all others of the genus in the absence of lateral furrows on the glabella. *Quadraticephalus* (?) *minus* Endo, 1944, may not belong to the Ptychaspinae.

Distribution:—Fengshanian; Shantung, Shansi, Hopei, Liaoning and Korea.

Quadraticephalus coreanicus Kobayashi, new species

Plate XX, Figures 2-6, Plate XXI, Figure 13, Text-figure 12d-e.

1935.   *Quadraticephalus manchuricus* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 320, pl. 6, figs. 1-5, non 6-7.

As the result of the study on fresh materials, I was inclined to think it better to distinguish the South Korean form from the Liautung form (1931) specifically, because the outline of the glabella is always less conical or almost cylindrical and the free cheek much broader in the former than in the latter.

The free cheek in figs. 3-4 gives a good idea of the dorsal and ventral features. By cutting a cranidium, it was found that there is no doublure beneath the frontal border. Therefore there must be a rostral plate between the doublures of the free cheeks.

A tiny cranidium in fig. 13 belongs to an immature form of this species. Its glabella is gradually tapering forward and the posterior furrows are short, but otherwise it agrees well with the adult form.

Occurrence:—Fengshanian; Sho 1 and Sho 19.

Quadraticephalus quadratus Kobayashi

Plate XIX, Figure 11.

1935.   *Quadraticephalus quadratus* Kobayashi, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 320, pl. 6, fig. 8.

The chief distinction of this species from the preceding is the relatively broad glabella.

Occurrence:—Fengshanian ; Sho 1.

Quadraticephalus elongatus KOBAYASHI

1935. *Quadraticephalus elongatus* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2,* p. 321, pl. 6, figs. 6–7.

On this occasion the designation of the illustration is corrected, because the specimens in figs. 6–7 are errneously cited as *Q. manchuriensis.*

Occurrence:—*Dictyites* zone of Kasetsuji and Dotenri.

Subfamily Saukiinae ULRICH and RESSER, 1930

Croixan *Saukia, Prosaukia, Saukiella, Calvinella* and *Tellerina* are all reported to occur in Eastern Asia, although more material is needed to confirm the generic reference of certain forms. *Prosaukia* and some other saukids are further reported from Australasia (ÖPIK et al. 1957). Saukids in Kashmir (REED, 1934) do not belong to neither the Saukinae nor the Ptychaspidae. Two saukids are described from the Upper Cambrian of Iran by KING (1937). One is *Saukia iranicus* and the other *Iranaspis harrisoni*, (text-fig. 13a). The cranidium of the latter is so closely allied to *Tellerina paichiaensis* KOBAYASHI, 1933, that no distinction of generic value can be made. The pygidium found with the cranidium of the former on the same slab is, however, different from that of *Tellerina* and very much like that of *Tsinania ceres.*

Iranaspis is closely allied to *Plethopeltella* KOBAYASHI, 1942, whose type-species is *Plethopeltis resseri* KOBAYASHI, 1931. The glabella is parralel-sided in the latter genus, but gradually tapers forward in the former genus. A shallow marginal furrow is present in the former, but absent in the latter. LOCHMAN (1959) combined the two genera in the Iranaspidinae and placed this subfamily in the Leiostegiidae. It is, however, more probable to indicate a branch of the Ptychaspididae which differs from the Saukinae merely in the smaller size of the eyes and the low relief of the associated pygidium.

Eosaukia, Sinosaukia, Wedekindia and *Anderssonella* are indigenous to Eastern Asia. *Ptychaspis (Anderssonia) tani* SUN, 1924, (text-fig. 13c), is the type-species of the last which is different from all of the precedings in the possession of the fairly large frontal limb, and the expansion of the glabellar outline. As noted by SUN, it may be related to *Conokephalina*, s. l. The associated pygidium is, however, typical of the Saukinae.

LOCHMAN-BALK (1959) pointed out that *Wedekindia* SUN, 1935, is preoccupied by *Wedekindia* DUNBAR and HENBEST, 1931, named for a fusulinid genus. SUN's genus is founded on the crandium of *Wedekindia cylindrica* SUN, 1935, (text-fig. 13d), which looks almost identical with *Saukiella paiensis* RESSER and ENDO, in KOBAYASHI, 1933. Therefore SUN's is possibly synonymous with *Saukiella.*

Genus *Eosaukia* Lu, 1954

1954. *Eosaukia* Lu, *Acta Pal. Sinica, Vol. 2, No. 2*, p. 144.
1957. *Eosaukia* KOBAYASHI, *Jour. Fac. Sci., Univ. Tokyo, Sec. 2, Vol. 10, Pt. 3*, p. 375.
1957. *Eosaukia* Lu, *Index Fossils on China, Invert. Vol. 3*, p. 284.
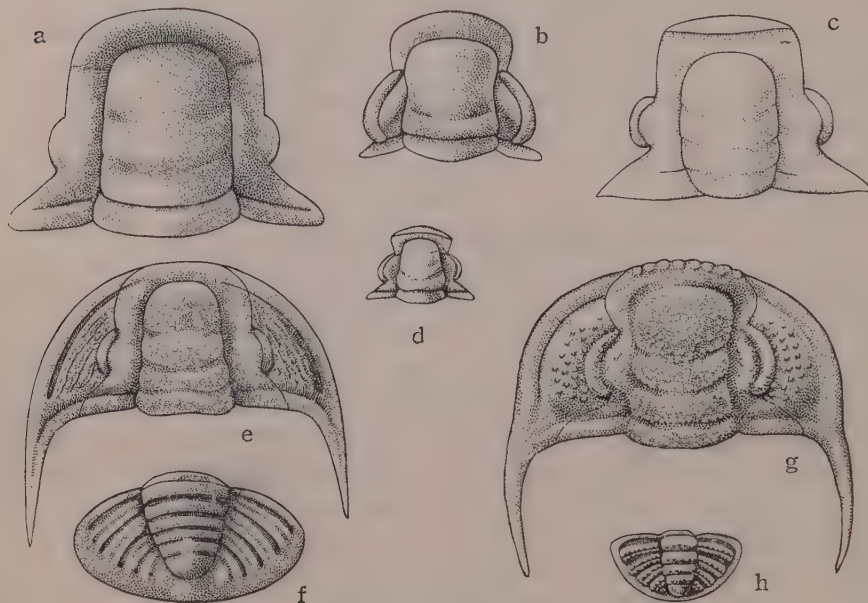
Figure 13.   Saukinae

a. *Iranaspis harrisoni* KING   b. *Platysaukia euryrachis* KOBAYASHI
c. *Anderssonella tani* (SUN)   d. " *Wedekindia* " *cylindrica* SUN
e-f. *Saukia iranicus* KING   g-h. *Sinosaukia pustulosa* SUN

Type-species :—Eosaukia latilimbata Lu, 1954.

*Remarks :—*Similar to *Saukia* and *Prosaukia*, but the fixed cheek relatively large and pygidium small and very wide in comparison with its length.   Thorax composed of 11 segments; test granulose.   The type-species was found in Ku-eichou with *Lotagnostus, Hedinaspis* and others.   " *Eosaukia* " *buravasi* KOBAYASHI, 1957, is described from the Tarutau sandstone in West Thailand.   As noted already (1956), *Ptychaspis walcotti* MANSUY, 1915, and some other saukids of Eastern Asia appear to have also small but relatively broad pygidia.   Therefore these saukids may be found distinct from Croixian genera, if complete shields are found.

*Distribution :—*Upper Cambrian; Kueichou, (?) Yunnan-Tonkin border and Peninsular Thailand.

Genus *Sinosaukia* SUN, 1935

1935. *Sinosaukia* SUN, *Pal. Sinica, Ser. B, Vol. 7, Fasc. 2*, p. 51.
1955. *Sinosaukia* HUPÉ, *Ann de Pal. Tom. 41*, p. 196.
1957. *Sinosaukia* Lu, *Index Fossils of China, Invert. Vol. 3*, p. 284.

Type-species :—*Sinosaukia pustulosa* SUN, 1935, (text-figs. 13g–h).

A row of tubercles along the frontal margin of the cranidium is the unique feature by which it escapes from confusion not merely with *Saukia*, but also with all other saukid-genera. Otherwise, however, it looks a saukid cephalon having a pair of large eyes close to the mid-length of the glabella. The associated pygidium is small. In the lack of the interpleural furrows and depressed marginal border it agrees better with the Ptychaspinae than the Saukinae.

Distribution :—Fengshanian ; Hopei.

Genus *Saukia* WALCOTT, 1914

Type-species :—*Dikelocephalus lodensis* WHITFIELD, 1880.
List of Asiatic species :—
   Ptychaspis acamus WALCOTT, 1905.
   Ptychaspis cadamus WALCOTT, 1905.
   Ptychaspis campe WALCOTT, 1905.
   Ptychaspis suni GRABAU and SUN, 1924.
   Ptychaspis acamus punctata SUN, 1924.
   Saukia aojii KOBAYASHI, 1933.
   Saukia acama fengtiensis SUN, 1935.
   Saukia tieni SUN, 1935.
   Saukia ulrichi RESSER and ENDO, 1937.
   Saukia (?) *orientalis* RESSER and ENDO, 1937.
   Saukia iranicus KING, 1937, (text-figs. 13e–f).
The last has the cranidium typical of the Saukinae. Its pygidium is, however, intermediate between the Ptychaspidinae and Saukinae. Namely, its outline is elliptical, much broader than long and the marginal brim undeveloped, but the interpleural furrows are impressed as distinctly as the pleural furrows.

   Saukia (*Briscoia* ?) *vagans* REED, 1934, does not belong to the Saukinae.

Distribution :—Fengshanian ; Liaoning, Shantung, Hopei and Korea ; (?) Wanwanian *Cryptozoon* limestone of Hualienchai, Liaoning.

Genus *Calvinella* WALCOTT, 1914

Type-species :—*Dikelocephalus spinifer* HALL, 1863.
List of Asiatic species :—
   Ptychaspis bella WALCOTT, 1906.
   Ptychaspis walcotti MANSUY, 1915.
   (?) *Calvinella ulrichi* SUN, 1935.
   (?) *Calvinella* (?) *yini* SUN, 1935.
   Calvinella striata RESSER and ENDO, 1937.
   Calvinella diversa ENDO, 1937.
Distribution :—Fengshanian of Liaoning, Hopei, Shantung, South Korea and Yunnan-Tonkin border ; Wanwanian series of Chiufotang, Jehol and Chiushukou shale of Niuhsintai, Liaoning.

Genus *Prosaukia* ULRICH and RESSER, 1933

Type-species:—*Dikelocephalus misa* HALL 1863.
List of Asiatic species:—
    Dikelocephalus (?) *baubo* WALCOTT, 1905.
    Dikelocephalus (?) *brizo* WALCOTT, 1905.
    Ptychaspis angulata MANSUY, 1915.
    Ptychaspis angulata chinensis SUN, 1924.
    Prosaukia ulrichi KOBAYASHI, 1933.
    Prosaukia (?) *orientalis* KOBAYASHI, 1933.
    Prosaukia tawenkouensis SUN, 1935.
    Prosaukia resseri ENDO, 1937.
    Prosaukia rotundolimbata ENDO, 1937.
    (?) *Prosaukia brizoformis* ENDO, 1939.

See *Lichengia* for SUN's *Prosaukia brizo*. *Prosaukia middlemissi* REED, 1934, does not belong to the Saukinae.

    Distribution:—Fengshanian; Liaoning, Shantung, Yunnan-Tonkin border and (?) South Korea; Chiushukou shale of Niuhsintai, Liaoning.

Genus *Tellerina* ULRICH and RESSER, 1933

Type-species:—*Dikelocephalus crassimarginatus* WHITFIELD, 1882.
List of Asiatic species:—
    Ptychaspis callisto WALCOTT, 1905.
    Ptychaspis chinhsiensis SUN, 1924.
    Tellerina paichiaensis KOBAYASHI, 1933.
    Tellerina coreanica KOBAYASHI, 1935.
    Tellerina (?) *obsoleta* KOBAYASHI, 1935.
    Tellerina orientalis RESSER and ENDO, 1937.
    ? *Calvinella striata* RESSER and ENDO, 1937.
    Tellerina sulcatifera ENDO, 1937.

    T. orientalis and *C. striata* probably belong to an identical species with *T. chinhsiensis*, all of which occur in the same Wanwanian series of Niuhsintai, Liaoning.

    See *Iranaspis* for *Tellarina paichiaensis* KOBAYASHI, 1933.

    Distribution:—Fengshanian of Liaoning, Shantung and South Korea; Chiushukou shale of Niuhsintai, Liaoning.

Genus *Saukiella* ULRICH and RESSER, 1933

Type-species:—*Dikelocephalus pepinensis* OWEN, 1852.

    Saukiella peipingensis SUN, 1935 and *Saukiella tarutaoensis* KOBAYASHI, 1957, belong to this genus. See page 403, for *Saukiella paiensis*.

    Distribution:—Fengshanian of Hopei and Peninsular Thailand.

Saukiella sp.

Plate XIX, Figure 30.

1935. *Calvinella* sp. KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sect. 2, Vol. 4, Pt. 2*, p. 316, pl. 5, fig. 11.

The illustrated pygidium is 16 mm. wide and the axial lobe 6.3 mm. wide. The latter is composed of 5 rings and a terminal lobe; pleural and interpleural furrows well developed; marginal border of moderate breadth, concave and depressed. It agrees with "*Calvinella*" sp. from Dotenri fairly well, although the axial lobe is more cylindrical in that pygidium. This pygidium is referred to *Saukiella*, because of its close alliance to the pygidium of *Saukiella pepinensis* (OWEN). Their chief distinction lies in the breadth of the axial lobe greater in the Croixian species than the Korean one.

Occurrence:—Fengshanian at Sho 1; *Dictyites* zone at Dotenri.

Genus *Platysaukia* KOBAYASHI, new genus

Diagnosis:—Saukioid having the cranidium of low convexity, very large palpebral lobe and broad glabella contracted near the middle length.

A further information is given in the description of the type-species, *Platysaukia euryrachis* KOBAYASHI, new species.

Platysaukia euryrachis KOBAYASHI, new species

Plate XIX, Figure 12, Text-figure 13b.

Description:—Cranidium not much inflated; glabella broad, somewhat contracted at a little anterior to the center; frontal lobe gently slant; posterior furrows shallow toward axis where they are united; occipital ring a little narrowing laterally; dorsal furrow distinct; palpebral lobes large; intra-ocular part of fixed cheek swelling up; postero-lateral limb of the cheek very small; preocular part of the cheek narrow and united with simple frontal border; marginal groove absent; anterior facial sutures slightly divergent forward; test smooth.

Occurrence:—Fengshanian; Sho 1.

Family Uncertain

Genus *Mareda* KOBAYASHI, 1942

Mareda mukazegata KOBAYASHI

Plate XIX, Figures 31–32, Text-figure 14b.

1935. *Pterocephalus busiris* SUN (non WALCOTT), *Pal. Sinica, Ser. B, Vol. 7, Fasc. 2*, p. 66, pl. 4, figs. 19–20.
1942. *Mareda mukazegata* KOBAYASHI, *Japan. Jour. Geol. Geogr. Vol. 18*, p. 297, text-fig. 2–3.

SUN's specimen in fig. 19 on pl. 4, 1953, i. e. text-fig. 2 in my paper, 1942, is the holotype. Once I (1935) suggested *Lioparia* in the Anomocarinae for the reference of *Pterocephalia busiris* WALCOTT. HUPÉ (1955) placed *Mareda* in the Anomocaridae.

A few specimens from South Korea reveal the typical aspects of this genus. Unfortunately they are imperfect, but agree much better with *mukazegata* than WALCOTT's *busiris*. In the type pygidium of *mukazegata* the interpleural furrows are weaker on the left than on the other side of the pygidium, but they are usually still weaker in the South Korean form. Therefore it may turn out a new species, if a good material is available.

Occurrence:—Fengshanian; Sho 1. The cranidium of *Platysaukia euryrachis* and several pygidia of *Tsinaina ceres* are found in association with this species. At Lincheng, Shansi.

Figure 14.   *Mareda* and *Hsiaoshia.*
a. *Hsiaoshia quadrata* ENDO
b. *Mareda mukazegata* KOBAYASHI

Genus *Hsiaoshia* ENDO, 1944

1944. *Hsiaoshia* ENDO, *Bull. Centr. Nat. Mus. Manchoukuo, No. 7*, p. 91.

Type-species:—*Hsiaoshia quadrata* ENDO, 1944, (text-fig. 14a).

Remarks:—This genus is founded on the pygidium similar to *Hamashania pulchra* KOBAYASHI, 1942, but different in the presence of broad shallow posterior sinuation. This genus is much older than *Hamashania* since the pygidium was procured from Tangshihan limestone of Hsiaoshih with *Manchuriella tenuilabrosa* ENDO.

Occurrence:—Tangshihan; Liaoning.

Incerta Sedia

Genus *Myona* KOBAYASHI, 1935

Myona flabelliformis KOBAYASHI, 1935

Plate XX, Figure 1.

1935. *Myona flabelliformis* KOBAYASHI, *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. 2, Vol. 4, Pt. 2*, p. 325, pl. 14, figs. 20–21, text-fig. 33.
1955. *Myona flabelliformis* KOBAYASHI, *Trans. Proc. Pal. Soc. Japan, N. S., No. 20*, p. 95, pl. 14, figs. 5–7.

Distribution:—This is a leading member of the Kushan fauna which is widely distributed in South Korea, Shantung, Liaoning and Shansi (LU, 1954).

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The Cambro-Ordovician Formations and Faunas of South Korea,
Part VII, Palaeontology VI.

Supplement to the Cambrian Faunas of the Tsuibon Zone with
Notes on some Trilobites Genera and Families

Plate XIX

Explanation of Plate XIX
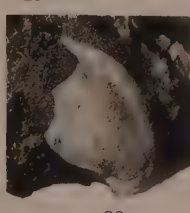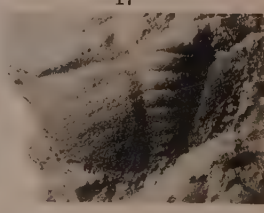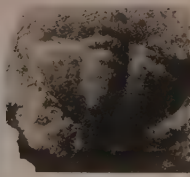
T. Kobayashi

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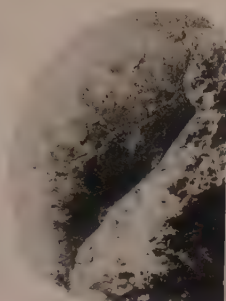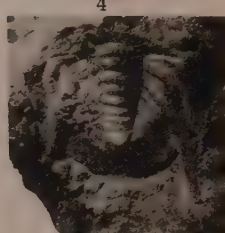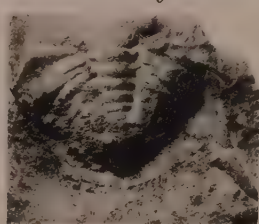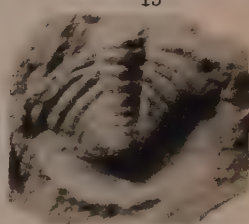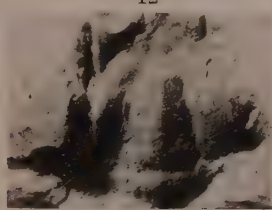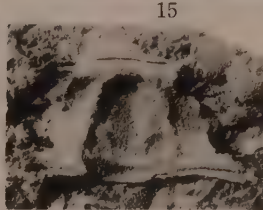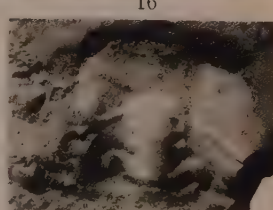
T. Kobayashi

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Part VII, Palaeontology VI.

Supplement to the Cambrian Faunas of the Tsuibon Zone with
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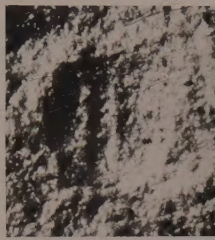
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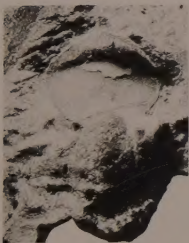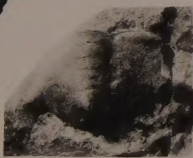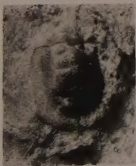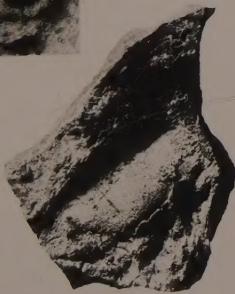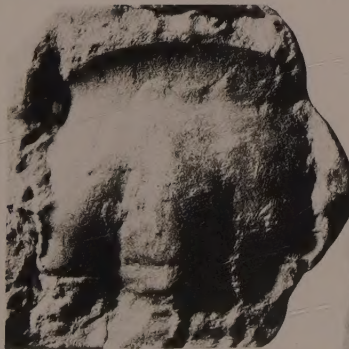
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